Puppy Pal

Senior Design Group 11

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Table of Contents

1 Executive Summary

Puppy Pal's express purpose is to entertain the owner's dog autonomously. This will be accomplished by designing a device that accurately simulates the movements and sounds of a real animal. This main device will be spherical, and will be referred to as the Ball. The reason for choosing a ball over conventional four-wheeled designs is durability, a fully enclosed ball allows no external components, which could easily be chewed off by a persistent dog. The ball will be the only device interacting directly with the dog, and all other devices will support the function of the ball. When animals play, their movements are sporadic and they audibly communicate. This device's autonomous guidance system will mimic these actions using a location detection system and pseudorandom motion sequences, and an audio subsystem will generate intermittent animal sounds. The ball should not wander aimlessly into potentially unsafe areas, so a user definable play area will be created using a base station and the location detection system. The base station will also act as a wireless charger, and will be referred to as the Base Charging Station. In order to avoid this toy becoming a nuisance, the device should be able to intelligently adjust its state when the dog is awake and ready to play, and when the dog is sleeping and doesn't want to play. This function is very important to avoid exhausting and annoying the dog, and will be implemented in two subsystems. The first system will be a collar attachment worn by the dog, which will determine when the dog is moving, and signal the main device. This device will be simply referred to as the Collar. The second system will be a proximity sensor located on the Base Charging Station, and will be used to determine when the dog has entered the play area. Both devices must be triggered before the ball begins moving, because the dog should be allowed to sleep without being disturbed while in the play area. This requires that the motion detection systems work together to determine when the dog has gone to sleep, which will be defined by a sharp decrease in movement, whether or not the proximity sensor detects the dog in the play area. The sleep function will also allow an extension of battery life. Puppy Pal should be capable of sustaining play intermittently for an entire work day, including a one hour commute to work, eight hours at work, and a one hour commute home. This system, the ball in particular, must be extremely durable, as it will be exposed to outdoor weather, knocked about during play, and even chewed on if the dog manages to catch it. The Base Charging Station and Collar will also be exposed to elements and potential chewing, and must be designed with matching durability. In addition to the autonomous mode described above, Puppy Pal will have a user interaction mode, controlled by an Android application. This function will allow the owner to play with their dog in a more traditional sense while not requiring any additional equipment for those already having an Android phone, capable of Bluetooth communication. This application will allow users to control the settings of the device, and will act as a remote control, allowing the device to operate in an area governed only by the range of the Bluetooth communication equipment on the two devices.

2 Project Description

2.1 Project Motivation

Dogs provide hours of entertainment and years of loyal companionship to their owners, but all too often have the undesirable habits of rummaging through the trash, digging holes, and chewing on household items. These habits are inconvenient to the owner and can have serious health consequences for dogs, since much of what they eat in the trash can be unhealthy and even toxic. Many owners don't realize that the root cause of this behavior is simply boredom. Boredom is easily prevented, but often occurs while the owner is away and thus can become a difficult problem to mitigate. Many people have tried to give their dog a bone or chew toy, but these quickly become uninteresting because of the monotony and lack of feedback. These problems have been addressed by squeaking toys, scented and flavored and countless others, but all fall short when it comes to long term distraction. After struggling to find something capable of long term distraction, it was concluded that only other living beings provided sufficient entertainment. Dogs will chase squirrels, lizards and even each other, but this often can't be accommodated in an urban household, so what better way to distract them that with a toy built to mimic this behavior.

2.2 Goals and Objectives

The overall goal of this project is to provide all day entertainment for dogs to avoid the destructive behaviors that boredom causes. This requires that the device be capable of capturing the attention of the dog, and retaining that attention until the dog is tired enough to rest. The best way for this device to capture and retain the dog's attention is to simulate something that is already instinctually interesting to all dogs, another animal. The simple solution of leaving another animal for the dog to play with overlooks the tendency for the animals to play destructively together, therefore, the best solution is to simulate an animal that will only play in a safe and non-destructive manner. In order to effectively simulate an animal, this device should be capable of impulsive and apparently spontaneous motion, suggesting the need for a lightweight design and a motor capable of providing quick bursts of movement. This product must be able to handle the wear and tear of everyday play while still being visually stimulating, which will be accomplished through enclosing all parts within a hard plastic sphere which will be masked with a replaceable fabric cover. The sphere is important because there are virtually no places that can be chewed on or torn off. The all-day duration requires a sleep function that takes advantage of the time when the dog is napping, allowing the dog an undisturbed rest while monitoring the dog to allow for restoration of entertainment when the dog has woken up.

2.3 Project Specifications and Requirements

2.3.1 Durability

Durability plays a huge role in terms of overall specifications of the device, with the project being produced to interact with household pets, specifically more with dogs, the device was primarily designed to be highly durable against a wide variety of situations that may threaten the internal electrical structure. Since dogs have a habit of salivating on their toys, the device has a spherical enclosure that will resist any significant amount of saliva from the dog in seeping through into the internal electronic hardware of the system. Many dogs are known to play rough when they are put into a playful mood, they can potentially often tear and throw around their toys that can eventually cause destruction over a period of time, especially if there is some sort of fragile circuitry involved inside of the device. The device will be durable enough to withstand approximately maximum impulse forces that the dog may deliver to the system and has the required protocol for the hardware inside to stay protected in order for the device to operate to optimal standards. In addition, the enclosure was that used to meet the requirements to be made from a material where it will be highly difficult for a dog to chew up and expose the electrical circuit. There are a wide range of materials that can potentially be used that may protect against the issues previously stated. Specifically, a material that has a combination of requirements in terms of being highly durable to the dog's habits, a low weight, and to have a feasible rolling resistance to provide adequate mobility on carpet, tile, or wooden surfaces would be the most optimal choice for a plastic enclosure. Table 2.1 provides informational specifications on different types of plastics that can be used as an enclosure for the device.

Plastic Type	Water Absorption in 24 hours (%)	Tensile Strength (PSI)	IZOD Impact (ft-lbs/in)	Compression Strength (PSI)
Acrylonitrile Butadiene Styrene (ABS)	0.3	6500	7.7	6750
Polycarbonate	0.2	10,500	12.0 – 16.0	11,000
Acrylic	0.2	10,000	0.4	17,000

Table 2.1 Plastic specifications [1] [2]

As shown in the Table 2.3.1, all the elements are approximately equal in terms of water absorption. Which the numerical range of 0.2 to 0.3 percent would be a logical value, because the device is not intended to be exposed to any sort of liquid for a long periods of time. Ideally, the device is expected to interact with a low volume of liquids, such as saliva, throughout the day. Tensile Strength (material breaking under tension) may be neglected depending on the dog, due

to the enclosure being spherical and with dogs having limited physical capabilities in pulling on the material, but can be looked at as a guideline in making a final decision on choosing an enclosure. IZOD impact (amount of energy a material can absorb before it breaks) and compression strength (material breaking under compression) are significant specs to look at because the device will primarily be in situations where the material is compressed and additionally required to resist impact from a dog or if the device hits a wall or falls down some stairs. The device can potentially be put in a position where the dog is laying on it, under these circumstances, the most reliable enclosure would have to be determined based on the best compression strength with respect to the average maximum weight of all household species of dogs.

2.3.2 Mobility

Movement inside a small space is a key priority. As mentioned in the section above, if the dog gets a hold on to the device, it will be easier for the animal to destroy. The primary goal in terms of mobility is not necessarily in terms of high speed or quickness, but more along the lines of the system evading or engaging the dog. The purpose of evading the dog will give the device a lower chance of the dog destroying it and also it will keep the dog engaged and occupied.

The velocity of the system would be significant enough to evade the dog in a small area such as a room in a house, thus the motors would provide enough torque to cause rotational movement of the spherical enclosure and cause significant translational movement of the center of mass of the device at this suggested velocity. Theoretically, that is neglecting any internal power losses, to determine an optimal torque range to cause the device to move will require many mechanical equations.

Ideally, the suggested velocity can be used to conclude how much current will be needed to drive the motors. The device will primarily be used in a household or an apartment, it will be designed in order to move swiftly and thoroughly across carpet, tile, or a wooden surface of some sort. Depending on the material of the floor, the speed of the device will vary, especially on carpet where the coefficient of friction and rolling resistance will be significantly higher in comparison to the tile and wooden flooring. For optimal mobility, it is safe to choose the material and torque needed, assuming it will be designed to be used on carpet.

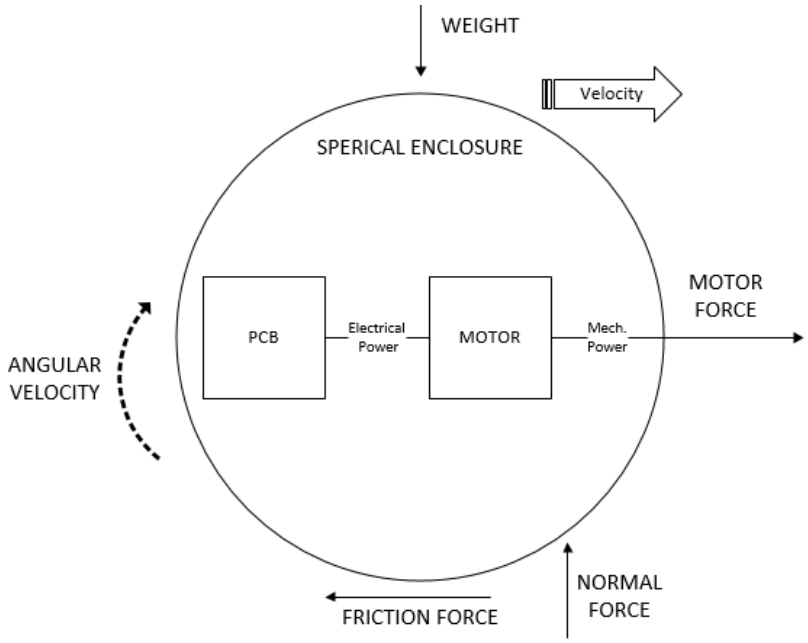

Figure 2.1 Free-body diagram of device

2.3.3 Autonomous Movement

Autonomous movement is critical to the Puppy Pal. It is a key feature that separates it from other similar devices like the Sphero. The point of having autonomous movement capabilities is to simulate human movement while no human is present. This keeps the dog entertained even while no one is present. The best way to simulate this is to allow the users to program their own modes into the Puppy Pal. This is done through the Android device. Users should be able to draw a path in the Android program and send it to the device through a sequence of messages. The embedded software should be able to hold a list of these predefined paths, and when the system is set into autonomous mode, either a specific path is run or all the paths are cycled through at a rate that is set by the user. There should also be a “random” mode that makes random changes to the systems speed and direction in predefined intervals of time.

All of these modes should be able to be commanded into by sending a specific message from the Android device. The user should also be able to send a message that lets the system know which autonomous settings should be set next time the system is to go into autonomous mode, either again by the user or by the dog’s collar system setting it off. The movement of the device is to stay within a certain limit of its surroundings. This plane is known as the “play area.” When the system is running in a random autonomous mode, it should not go outside the boundaries of the play area.

2.3.4 Remote Control

A secondary mode, when the system is not autonomous, will be under user control. This will provide the user a manual override, in terms of controlling the device. The system will need to be interfaced wirelessly to an Android device either by developing a simple application for the user to use or using some type of serial interfacing software to send data to the MCU. The Android device will retrieve inputs from the user. The goal of the remote control option is to give the personnel a simple way of controlling the system by sending commands via a wireless signal, which will be translated in to instructions to the microcontroller to update how the motors in the system will operate. The system will need hardware to accept the user signal and then transitioned into the system processor. Since this device is intended to function in a house, an RF signal that can be implemented in short distances can be used, such as Bluetooth. Using Bluetooth will a simple way to interface an Android device to the main system. In a basic perspective, the user input will designate the android device to send out a limited number of signals: a signal to turn on device, a data signal to move forward, a data signal to move backwards, and two signals that determine right or left turns. Figure 2.2 illustrates a simple block diagram of remote control application of the device.

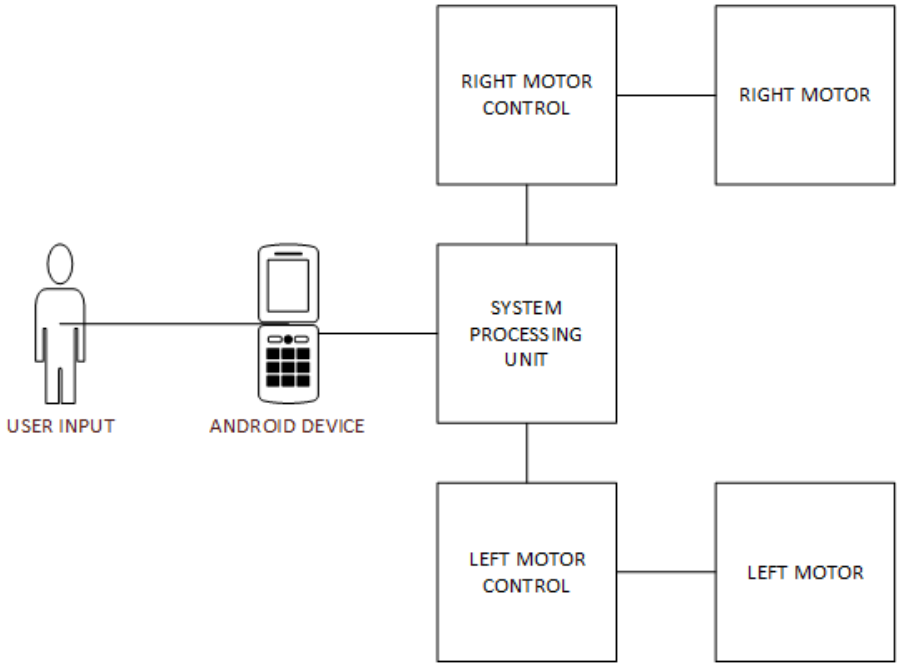

Figure 2.2 Simple Block diagram illustrating RC control for device

2.3.5 Wireless Charging

Puppy Pal requires wireless charging in order to allow for a fully enclosed, physically secure device with no external components or connections which

could be destroyed. The key factors affecting design of this subsystem are size and cost, power rating, and range from charging coil to receiving coil and the efficiency over the range. Components used in the wireless charging subsystem will be either certified or compatible with the Qi Version 1.1 standard from the Wireless Power Consortium (WPC), where applicable, in order to create a more robust design. WPC 1.1 defines the type of inductive coupling and the communications protocol, allowing the receiver to be charged by any other WPC 1.1 certified charger, and selection of components which were designed to the same specifications, to obtain better efficiency and minimize the chance of error in the design. Power rating and efficiency in the wireless charging module are important for lowering the charging time as well as conserving household power, but will have minimal impact on the system's battery life for a given charge, therefore size and cost will be the major driving factors. Size of the receiving coil is very important due to the positioning constraints of a sphere, the smaller the coil, the closer it can be to the transmitter coil, making the link more efficient. The required components for this subsystem are a reliable and regulated power source, a wireless power transmitter connected to a transmitting coil, a wireless power receiver connected to a matched receiving coil and a charging module. The power source used will be a household outlet using standard 120V AC power at 60Hz, which will be stepped down, rectified, filtered, and regulated before being fed as DC power to the transmitting device. The transmitting device will convert a DC power source into a wireless power signal that can be efficiently transferred from the transmitting coil to the receiving coil and will provide a communications link to the receiving device for control and monitoring. The receiving device will convert the received wireless power signal to a regulated DC output. The charging device will use the regulated DC output from the receiving device to safely and efficiently charge the battery system.

2.3.6 Motion Detection

The primary need for a motion detection system arises from the need to keep the dog occupied at all times while awake without becoming a nuisance when the dog is sleeping, however, this system will also enable an intelligent sleep mode to extend battery life. The motion detection subsystem must be capable of independently determining when dog is awake regardless of proximity, within the limitations imposed by the communication subsystem, and when a dog is within the region of play. The requirement of determining that the dog is awake suggests that this device be located on the dog, and thus will require a communications system to relay information to the main processor on the ball. This device will be attached as a collar and must be of minimum size in order to avoid causing discomfort. This system will have to intelligently discriminate between a dog adjusting while sleeping and a dog that is fully awake, to avoid irritating the dog. This subsystem must also determine when play is over, to enable sleep mode and allow for longer battery life. The requirement for determining when a dog is within the play area means that this subsystem could be located either on the ball or on a separate device. Placing this device on the

ball imposes complications because the ball is not always located at the center of the play area and is not always oriented the same way, however, placing this system on the charging system can eliminate both of these issues. This now means that the charging station will also require a communications subsystem to relay information to the main processor on the ball. Since this device is intended for use both indoor and outdoor, any sensors, particularly infrared or optical sensors, must be capable of properly functioning in full view of the sun. Factors important in choosing components for the base charging station's motion detection subsystem will be the range of detection, the method of detection and experimental effectiveness, and its cost. For the final project, the only motion detection system implemented was a collar containing an accelerometer which was used to determine if the dog was moving and communicate this data to the ball.

2.3.7 Sound Projection

Once again as stated previously, a specification of the device is to keep the dog engaged; a way of doing that is implementing a sound projecting subsystem to attract the animal to the device. A simple way of looking at it is, if the dog is at a far distance from the device, the system processor will turn the output connected to the sound projection subsystem on to play a brief sound clip to grab the attention of the dog.

The sound system will be triggered by a motion sensing system that will measure the activity of the dog, for example if the dog has a consistency of movement and is appeared to be active, the sound will be activated to lure the dog towards the device. However, if the sensor reading displays inactivity it will assume the dog is laying down or sleeping which results in the sound clip not being played. The sound system can be either a small speaker that can have specific sounds downloaded into it or a piezoelectric sound generator. As shown on the block diagram in Figure 2.3, the MCU output pin is connected to the input of the speaker or sound projection device; the microcontroller output is triggered high if the motion sensor reads in a threshold value that represents consistent movement by the dog. A high output voltage turns on the sound generating device to attract the dog.

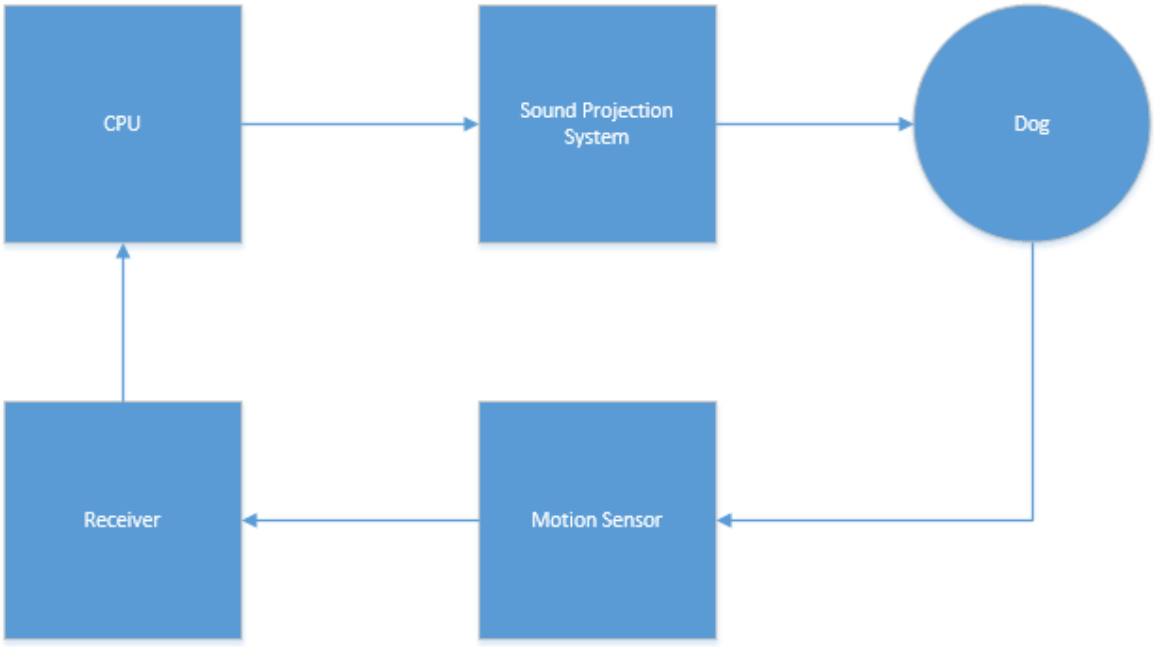

Figure 2.3 Simple Block diagram illustrating sound projection control

2.3.8 PCB

The device will need three PCB's; one for the main system that will be placed in the actual ball, one for the charging station, and another smaller one that will be placed on the collar of the animal. The PCB located in the ball will provide the main control of the entire system that will communicate with all of the other subsystems and will be used for motor control, sound projection, receiving data from Android device, and location detection from the charging station. The PCB on the charging station will be control the wireless charging and location detection of the ball. The PCB on the collar of the dog will be used to send a signal when there is motion detected from the animal. The hardware for all three PCBs will need three separate MCUs and three power sources to operate. The PCB in the ball will be powered by a rechargeable battery, which will need to be able to function coherently with the wireless charging hardware. The battery in the ball will be required to have enough power to operate two motors that will move the device. The charging station PCB will be powered by an AC voltage supplied from the wall socket (will be rectified to around 5 to 12 V). The PCB on the collar will be powered by a low voltage battery, a table displaying all the basic specifications of all three PCB's are shown below on Table 2.2. A simple block diagram is illustrated to show a visual representations of the placements of the three PCB in Figure 2.4.

PCB Location	Enclosure	Collar
Functionality	-Motor Control -Operate Motor -Android Communication -Sound Projection -Location Detection (Receive Location) -Motion Detection (Receive Detection)	- Motion Detection (Transmit Detection)
Power Supply	DC Voltage -12 to 24 V (Rechargeable)	DC Voltage- 3.3 to 5 V

Table 2.2 Specifications on each PCB.

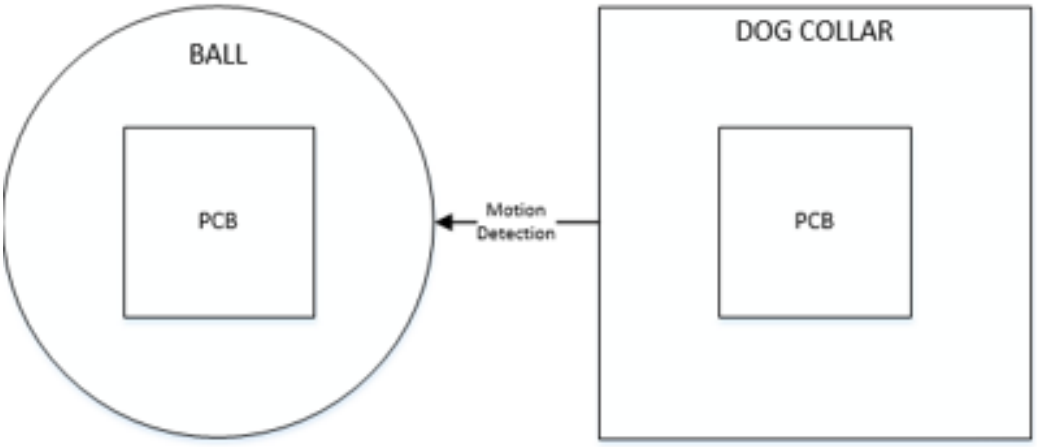

Figure 2.4 Block Diagram illustrating PCB locations of entire system

3 Research Related to Project Definition

This project's design and construction demanded specialized knowledge and experience. In order to build the best possible toy, the group's body of knowledge had to grow. Different techniques were studied and compared to decide what methods would work best in the design of Puppy Pal.

3.1 Existing Similar Projects and Products

To point research in the right direction, projects similar to the initial concept of Puppy Pal had to be studied. These were used to learn what modes of transportation and control were used, what had been successful, and what could possibly be accomplished within the required timeframe. The most important knowledge gained was the scale of the project; the project's objectives could be met.

3.1.1 Sphero

Sphero is a robotic ball toy. Owners control the toy's motion and the LED color displayed with a smartphone application. Sphero uses Bluetooth communication to receive its commands. It can also charge wirelessly. To track movement, a three-axis accelerometer and a gyroscope were installed.

In addition to the basic control app, Sphero's creators developed a series of programming environments to encourage Sphero owners to be creative and make their own apps. The apps range from setting a path for Sphero to follow to augmented reality racing and zombie fighting games.

Puppy Pal recreated the spherical shape, wireless charging, and Bluetooth communication features Sphero has. The great variety of apps developed for Sphero shows that there are many applications for this type of toy. Making Puppy Pal autonomous was not so seem so far-fetched.

In Figure 3.1, the insides of Sphero are displayed. This gives insight to the structure of Sphero. The wheels (part B) drive the ball to roll. The top slip bearing (part C) braces the structure, keeps the wheels from slipping, and helps to keep the internal structure parallel to the ground. This mechanical design is similar to that used in Puppy Pal.

Figure 3.1 shows the inside of Sphero and the assembled Sphero in its charging dock. Permission Pending.

Sphero's Android app interfaces are built off of a development kit provided by Orbotix. The development kit provides many Bluetooth routines for sending commands compatible with the Sphero. User interfaces are completely up to the developer, however. There have been numerous designs for controlling the Sphero from a cell phone, most modeled off of old video game and RC car controllers. One very popular approach is to have the forward/backward and left/right control independent of each other. Probably the most used method of control is to provide an object to move around across a two dimensional plane. Moving the object directly up the y-axis would make the Sphero go forward, and moving the object into quadrant II would make the Sphero go left, and so on. This approach proves to be the most intuitive and easiest to use because its simple design allows the use of one finger to operate the toy's movement. The first method is the GUI that Puppy Pal's Android software mimics. Aside from movement, apps also have the ability to control the LEDs inside the Sphero. Puppy Pal only has LEDS to indicate whether or not there is power and if the Bluetooth modules have connected to each other and/or a cell phone.

3.1.2 Remote Controlled Basketball Robot

In this project, a basketball moves along the ground based on input from a two-channel radio and receiver. Inside of the basketball, a hamster ball holds the chassis. The sides of the chassis are attached to the outside of the ball. This holds the chassis in the middle of the ball. A drive motor, servo, and steering arm are used for drive and steering. A gyroscope was also included.

The bottom of the steering arm holds the batteries and weights. With enough weight, the chassis is kept parallel to the ground despite the ball's motion. As the motor and servo rotate the steering arm in the desired direction, the rest of the ball is pulled forward to keep up with the new center of mass. The gyro senses the changes in rotation, allowing for control.

This robot's mechanical system would have been a straight forward solution to the mechanical design of Puppy Pal. The main obstacles of this design are the weight used, the construction or purchase of the chassis, and control. The use of only a gyroscope in this project left much to be desired in precision. If Puppy Pal had used this method, it would also include an accelerometer to achieve a more clear-cut sense of maneuverability than the basketball robot.

3.1.3 Segway

The Segway balances on two wheels using a system of sensors to follow the rider's center of gravity. Five gyroscopes and two tilt sensors are used to detect the rider's movement atop the Segway. This information is used by the transporter's control circuits to decide on the proper course of action: going forward, turning, stopping, or sitting still. If the mechanical system had used changes in the center of gravity to drive movement exclusively, Puppy Pal would have incorporated its own system of sensors to decide which direction is best and to balance quickly when sitting still. The Segway shows that such a system with built-in redundancies can be effective. However, size restrictions and the multiple delays in the construction and design of the mechanical system made the addition of a sophisticated feedback system a lost cause.

Figure 3.2 shows the forces acting on the Segway and its rider. As the rider moves, Segway uses the data from its sensors to find what action will keep the rider balanced [3]. Unbalanced forces create toque and result in falls and injuries.

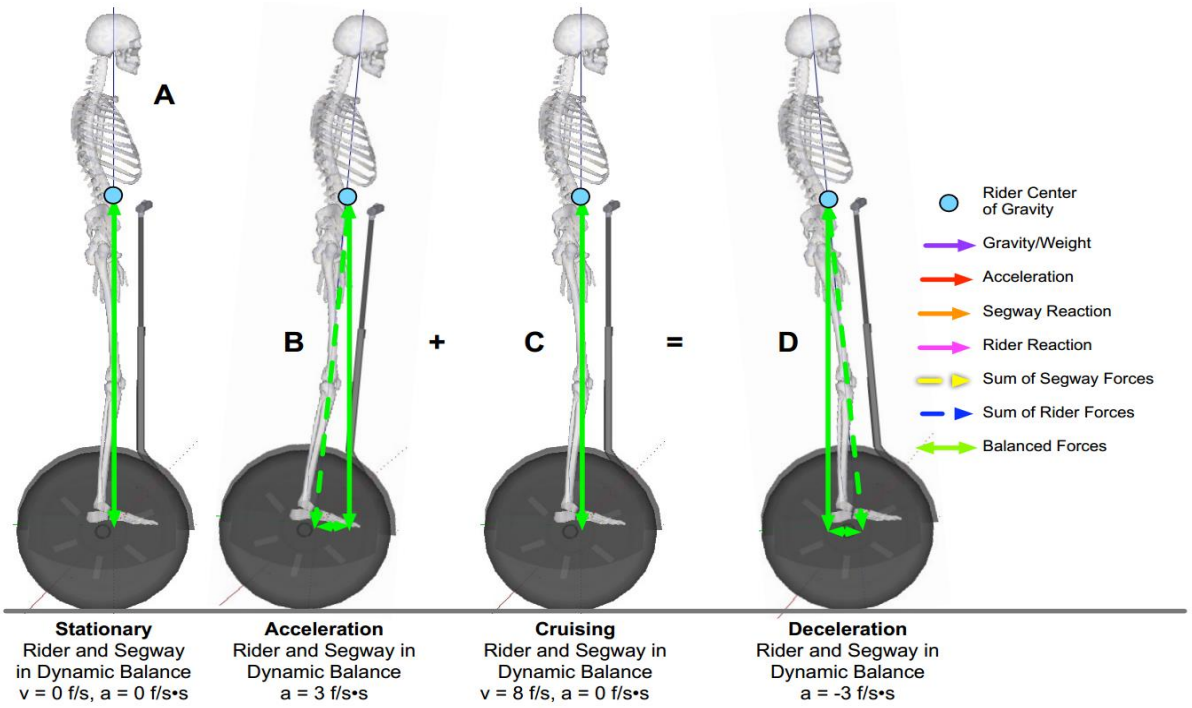

Figure 3.2 The balance of the forces acting on a Segway and its rider when stationary, accelerating, cruising, and decelerating. Reprinted with permission from Brian Hughes.

3.1.4 Stray Pooch

Stray Pooch is a senior design project that was built by students from Wichita State University in 2011. This project's goal, to be an interactive dog toy, is similar to Puppy Pal. Their robot was built using a large hamster ball. The mechanical system consists of two motors connected to a gearbox. Shafts are connected to the motors and the sides of the ball. As the motors rotate, the sides of the ball rotate and drive the ball forward. A similar system was used in Puppy Pal's mechanical system. Unlike Stray Pooch, the shafts were instead attached to wheels that were controlled by their own motors inside of the gearbox instead of being attached to the ball itself. The framework inside of the ball was made out of wood and aluminum. Combined with the electronics, the frame was too heavy to work properly; the center of the frame dragged along the bottom of the ball, slowing down the robot. This showed that weight had to be watched closely when constructing the mechanical portion of Puppy Pal. In their follow-up experiments, the Wichita group rebuilt the frame with aluminum. Aluminum is much lighter than wood, so the mechanical system worked more efficiently when the change was made.

This group used an Arduino to control Stray Pooch. Although there are many tutorials available for Arduino applications, the group's lack of experience made the coding part of the project very difficult. The Puppy Pal group members

combated the challenge of inexperience with teamwork and the agreement that there was always more to learn. For wireless communication, Stray Pooch used XBee modules. They communicate with other Arduino devices that contain an XBee module in serial. Their method was not applied to the Puppy Pal's wireless communication system.

3.2 Relevant Technologies

3.2.1 Autonomous Robotics

There are plenty autonomous robotic systems in use today. Many are far more sophisticated than the Puppy Pal device will ever need to be, but there are plenty of ideas to take from these robots that can be integrated into the project. A popular autonomous robotic system is iRobot's Roomba, which is designed to clean a room by itself and find a path back to its "home base." There are a number of sensors on the device to help it perform this goal, some of which are an infrared receiver, bumpers on either side of the front, and a number of "cliff sensors," which are actually just more IRRs pointing down and checking the time difference between the signals bouncing back. The Roomba has a fairly trivial cleaning process. It typically starts out doing circles until it hits something, which it assumes is a wall, and tries to follow its contour. By making slight adjustments either left or right, if it finds that it has hit a wall after a few turns, it makes a major turn, usually around 180 degrees, and goes in a straight line until it hits another object, and repeats the process of trying to follow its contour. It's a fairly simple loop that utilizes all available sensors on the device. Where the true brains comes into this product is its ability to find its way to its charging station. This is something that the Puppy Pal tries to directly mimic. From a top down perspective, the Roomba is circular with a "front" and "back" designated by bumpers on the left and right. There are four infrared sensors on the front, back, left and right sides of the device. The Roomba home base also has an infrared emitter on it and when the Roomba needs to get back, it uses time difference of arrival (TDOA) to know which way to turn, takes a little move forward, and then does the same thing over again. Using this technique, along with the bumpers and wall detection, the Roomba does some crude path finding back to its charging station. There's a lot to be learned from this example, but the Roomba's physical dimensions are much greater than that of the Puppy Pal device. In other words, TDOA is significant with the Roomba whereas TDOA on the Puppy Pal would provide almost no difference, and the small differences would have to be accounted as error because of their sporadic changes.

There are other autonomous cleaning robots that achieve mostly the same effect which include the Neato XV-12 and Mint Plus. Aside from different detection features and shapes, these devices act in much of the same way as the Roomba. Urbie, the Urban Robot from NASA could also provide a lot of inside to the Puppy Pal because of its ability to maneuver in any kind of environment. The

design of Urbie is much more involved than the Roomba because it is specifically designed to go over rough terrains and even up and down small steps. Another unique feature of Urbie is that it contains two cameras to provide feedback of its surroundings. This also helps create a stereoscopic view of it location to help it avoid obstacles in its path. Because of Urbie's "car-like" appearance, many mechanical arms with capabilities of 360 degree rotation project from the top of the robot to help it flip upright in the case that it gets turned over. Although not in the same sense as Urbie, the Puppy Pal's inside can become turned over, however because of its enclosure no mechanical arms would aid the device in turning over. Instead the device naturally turns back over upon movement after it has become flipped. Moreover, it is not unnatural for the device to periodically spin around while inside its spherical housing.

A far newer and more advanced robot from NASA is the Mars rover Curiosity. Much like the Puppy Pal, the mars rover is controlled as well as autonomous when need be. This implies that it also has a messaging system, albeit much more sophisticated, much like the Puppy Pal. The autonomous capabilities are second hand compared to being controlled from Earth. Because of its extreme distance from its controllers, Curiosity sends data through ultra-high frequencies around 400 MHz. Occasionally the rover sends data directly to earth at a rate between 3.5 Kbits to 12 kbits. More often than not there is an orbiter that acts as an intermediary between the two. It is in scope of the rover for about eight minutes, and in that time sends about 60 Mbits of data.

Puppy Pal would not be capable of making use of all that data, but using an orbiter as an intermediate object did give new ideas to the way that Puppy Pal would be controlled. By having the charging station have its own processor and Bluetooth module, it could pick up on any Bluetooth messages being sent out, namely any message commanding the wheel speeds. This would allow the base station to keep a decent track of where the Puppy Pal is at any time, and allow it to navigate the device back to a close range of the charging station. From there more accurate device could allow precision docking to begin charging. Figure 3.3 shows the similarities between the data flow of the orbital and the Puppy Pal device, assuming this paradigm was chosen.

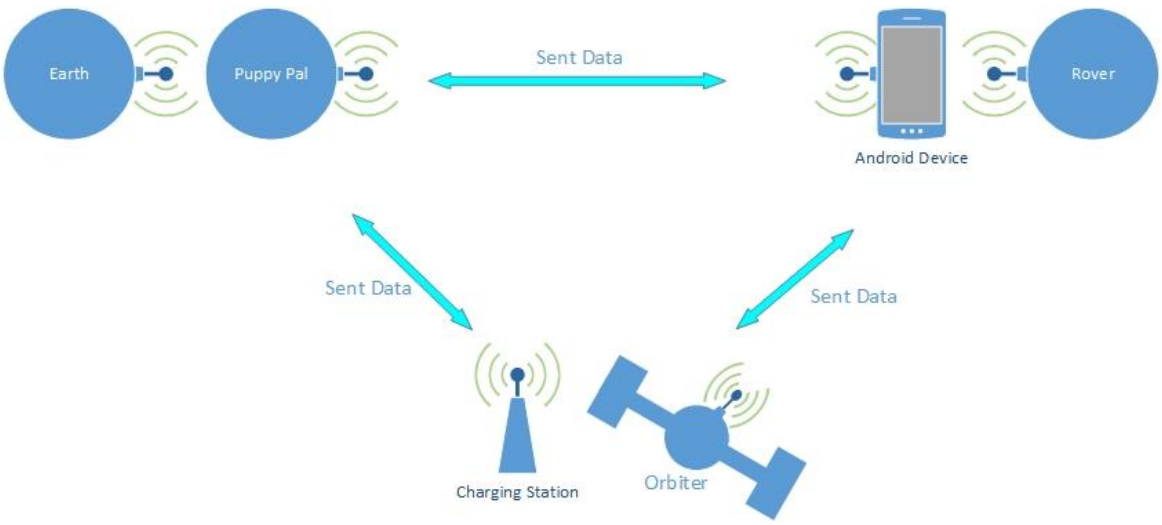

Figure 3.3 Similarity between Curiosity and Puppy Pal's communications

It is essentially the same, except that messages being sent from the Android device to the Puppy Pal are intercepted by the charging station rather than sent directly to it.

3.2.2 Android Remote Control Applications

There are many devices and projects that have integrated android devices into their system. In terms of using and incorporating Android application for the Puppy Pal, the Android device is used solely as a remote controller, as in controlling movement and potentially turning the device on or off. There are many techniques to interface Android device connectivity to a MCU. This specific section will display projects that use Android device integration and relevant techniques that may potentially be referenced.

A similar project that was observed used Android interfacing to control a remote control car [4]. The RC car's core processing unit uses the Arduino Uno development board with a Bluetooth module, specifically uses the HC-06, to read in data sent from the Android device. In addition to the RC car using the Bluetooth functionality, it also incorporates the accelerometer embedded in the Android device. The Android application developed provided three different ways for the RC car to be controlled: tilting control, normal button control, and touch control. Tilting control requires no button use, the tilting motion of the Android device designates the motion of the RC car just purely using the built-in accelerometer in the Android device. To elaborate, if the user tilts the Android device forward, then the RC car will accelerate forward, if it is tilted backwards the car goes backward, left and right tilts will result in right and left turns respectfully. The normal control displays five commands on the touchscreen of the Android device for the user to push. Each command represents a direction

the RC car can move. The five display commands represent the direction of motion, which are: forward, backwards, left, right, and OFF. Touch control displays a reticle in the middle of the display on the Android device, this reticle is representative of the RC car. If the user wants to move the RC car using touch control, the user will have to drag the reticle in the direction of desired movement of the RC car. Figure 3.4 illustrates the three control options.

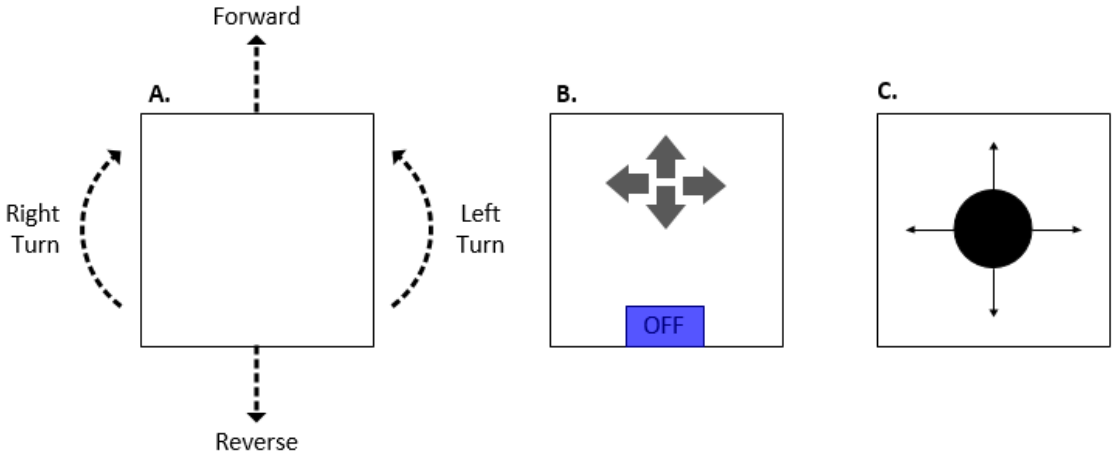

Figure 3.4 Illustration of three Android control methods: A) Tilt, B) Button, C) Touch.

The RC car project uses the CxemCar 1.0 Android application developed in the Eclipse IDE. The version of the Android device must be greater than 3.0 in order for the application to control the motors. The Android device is configured to the Bluetooth module on the car by connecting and searching for the module in the Bluetooth settings on the Android device. The CxemCar application uses the MAC address of the Bluetooth module to directly connect to the RC car, which finalizes a wireless serial connection between the two hardware devices, and data can be sent using the UART functionality on the Arduino Uno. The CxemCar application has many settings that can be configured. The application can edit the output characters representing a specific direction of motion the user can send to the Bluetooth module, changing the accelerometer sensitivity from the Android device, editing the maximum/minimum values on right/left PWM values, and other settings that can be configured.

Another similar project designs a home automation system using Bluetooth [5]. The basic idea of the system is to control devices such as lights, air conditioning, fans, and other around the home products that are limited to an ON/OFF functionality using a mobile device. The project reads in data from a HC-05 Bluetooth module. Unlike the RC car project as previously stated, the home automation system uses an Android application called BlueTerm, which is an emulator for serial devices that use Bluetooth to communicate between the system and the Android device. A user can use BlueTerm to directly send data to the module for the system processor to read in. The items that the user wants to

control will be connected from the PCB to the relays of those items. Each item that the user wants to control, specified in the MCU coding, will have a specific output pin and an assigned ASCII character affiliated with it to either turn it on or off. The BlueTerm application allows the user to send the specific ASCII character directly to the MCU in order to control the connected device. This project shows a method in connecting the Android as a controller to multiple devices. Figure 3.5 provides a block diagram on how Android devices can be connected to multiple devices or systems that can be controlled within a household.

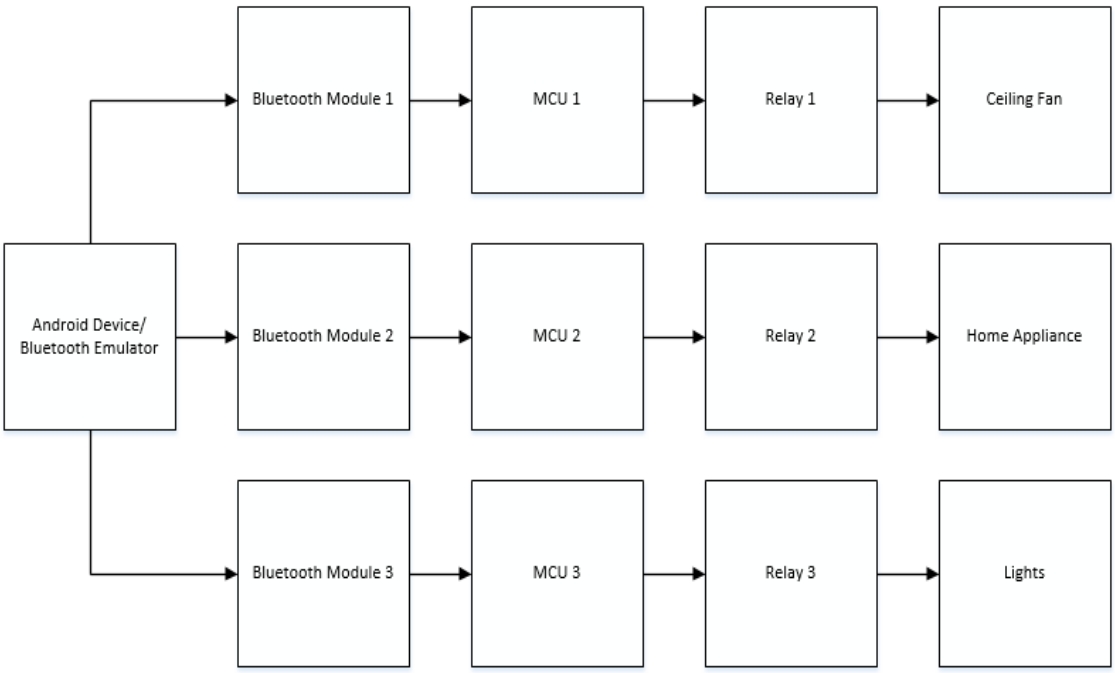

Figure 3.5 Block Diagram illustrating Android control over multiple systems

3.2.3 Location Detection

Puppy Pal requires a location detection subsystem in order to keep the dog safe, if Puppy Pal simply rolled around with no location feedback it could potentially roll into an unsafe area like a road, or undesirable area, like the pantry. The location must be capable of working with the control and mechanical subsystems to keep Puppy Pal within its assigned area of play within normal circumstances, meaning it is not being forced out by an external force. The location detection subsystem should also be capable of guiding Puppy Pal to return to its area from any place that the mechanical subsystem is capable of doing so, after it is carried off course by an error or external force. The key factors of the location detection subsystem are accuracy, precision, size, complexity of implementation, additional hardware, and cost. The location detection subsystem must also be capable of accurately providing velocity data, or primary data must be accurate and be

updated frequently enough that velocity can be derived from the position data source. This subsystem must be able to provide location measurements accurate and precise enough to keep the device within a defined radius of the charging station. The location subsystem must be capable of operating inside a building without a clear view of the sky as well as outside without Wi-Fi access. In order to achieve an accurate guidance system, the data produced by the location detection system must be simple enough to be processed in time to accept the next batch of data and for the data to still be accurate, or have a method for accounting for the distance travelled during processing time. In the interest of minimizing the complexity of integrating the location detection subsystem, a fully functional module would be ideal. Possible technologies to be researched and considered are a Global Navigation Satellite System (GNSS) such as the Global Positioning System (GPS) in the United States, Wi-Fi Position Systems (WPS) for use of the device in buildings or areas without a clear view of the sky, an Inertial Measurement Unit (IMU) with a software implementation of a Kalman Filter, and multilateration systems using electromagnetic, ultrasonic, or infrared sensors. In addition to these standalone systems, hybrids and augmentation systems will be considered. In the end, however, due to technological and budgetary constraints, all location detection systems were abandonded in favor of an open loop path selection system.

3.3 Strategic Components

3.3.1 Wireless Communications

There are two wireless communication systems that is implemented into the entire system. For example, there is a method of wirelessly communicating between the ball and the Android device, and the ball and the dog collar. Ideally, the distance between the collar and ball may vary. Since there are three different wireless applications that will be implemented in the system, potentially there can be multiple different components of wireless hardware modules that may be integrated into the system depending on functionality. For example, a GPS module can be used for location detecting, a Bluetooth module for an Android serial connection, and ZigBee hardware for reading input from accelerometer then sending data to the MCU. Table 3.1 compares simple characteristics between Wi-Fi, Bluetooth, and ZigBee technologies [6].

Technology	Wi-Fi	ZigBee	Bluetooth
Data Rate	2-11 Mbs	1 Mbs	0.25 Mbs
Range	100 m	10-100 m	10-30 m
Applications	Large data transfer at high speeds	Remote control, Sensor data	Android connectivity
Power Consumption/ Cost	High	Low	Medium

Table 3.1 Wireless Communication Comparisons.

3.3.1.1 Wi-Fi

Observing the data from Table 3.3.1, Wi-Fi can potentially supply the largest data transfer at the highest speeds and can give the user wireless control of the system without the user and device being in the same vicinity. In addition, Wi-Fi would potentially be a way to connect the Android device to the system and retrieve access to GPS capabilities on the mobile device. If the using Atmel's ATmega328P MCU, an Arduino Wi-Fi shield can be plugged into the PCB. The Wi-Fi shield uses WEP and WPA 2 encryption security protocol and the Arduino provides a Wi-Fi library to simply connect to a network [7]. However, Wi-Fi requires the most power and is more costly in comparison to the other technologies. If possible, Wi-Fi may potentially be implemented in the base charging station, as providing power will not be an issue. The overall system does not necessarily need to run any applications that require large data transfer capability or data transfer at a significantly high speed. Due to the complexity of implementing Wi-Fi, the best approach would be to use Bluetooth to integrate an Android device to the system and to use the ZigBee standard for other wireless communication applications. In addition for Wi-Fi was not used, would be the difficulty in trying to connect to the UCF network. It was observed that many other groups struggled with getting a conncetion.

3.3.1.2 ZigBee

The clear cut advantages of using ZigBee technology is that it is low cost and it is power efficient. ZigBee hardware is perfect for short distance wireless applications, for example using remote control, reading in wireless sensors, and monitoring. Since the system doesn't require transferring large amounts of data, ZigBee modules are an ideal candidate to be interfaced. Since ZigBee products can be used with small low voltage batteries, it can be used to transmit signals from the PCB located on the collar. Table 3.2 provides a comparison between different ZigBee modules. From the basic specifications listed on the table below,

the Digi International looks to be the ideal choice for a ZigBee module; it has a lower supply current to transmit and lower output power. The lack of data rate and line of sight range on the Digi International module can be neglected, as the system will not require transmission of data at a high data rate and the transmitter and receiver will operate at a close line of sight distance from one another ideally. Since the battery on the dog collar will be designed to operate on low power, the Digi International module illustrates the best alternative on transmitting a signal after the accelerometer has been activated.

Brand	Digi International (XB24-Z7PIT-004)	Atmel (ATZB-RF-233-1-CR)
Frequency Band	2.4 GHz	2.4 GHz
Line of Sight Range	120 m	1.96 km
Data Rate	250 kbps	2 Mbps
Supply Current-Tx	35 mA	157 mA
Supply Current-Rx	38 mA	7.5 mA
Supply Voltage	2.1 – 3.6 V	3 V
Output Power	1mW	112 mW
Price	17.00	19.68

Table 3.2 ZigBee/802.15.4 module specifications.

Since multiple wireless modules are implemented and the design is a 6 inch spherical platform, Zigbee wireless technology was not used. Zigbee was not chosen because of the many modules observed it appeared to use too many pins and some of them were too large for the design.

3.3.1.3 Bluetooth

Bluetooth is a wireless communication standard, which similar to the ZigBee standard has a frequency band of around 2.4 GHz that can be used as an application for short distances, lower power, and can be implemented using low cost modules. Bluetooth can potentially be used to communicate between different hardware wirelessly, in relation to the Puppy Pal, system control using an Android device. Even though the Android device will be in a visual line of sight within the Bluetooth module, it does not necessarily need to operate under those conditions because Bluetooth devices use a radio communications system. Bluetooth communications are usually divided into 3 classes in that all have their own specifications with respect to power and data transmission range. Table 3.3 displays the different Bluetooth classes.

Class	Max power (mW)	Max power (dBm)	Approx. range
1	100	20	100
2	2.5	4	10
3	1	0	1

Table 3.3 Table displaying the different classes of Bluetooth devices [8].

Bluetooth networks are implemented using the master-slave structure to control data flow. To elaborate, the device that is responsible for controlling communication data is referred to as the master, and slave devices usually just retrieve data. Master devices connect to a maximum of seven slave devices and can potentially communicate to them, however slave devices cannot communicate among other slave devices. The Bluetooth network would mesh perfectly into the Android integration of the Puppy Pal. The Android device will be the master device and the ball will be the slave device. In addition, if there is a Bluetooth communication method needed to transfer data to the charging station and dog collar, then those components will be referenced to be slave devices in the network. Figure 3.6 illustrates a simple Bluetooth network of the overall system; the charging station and dog collar may not need to receive data from Android device.

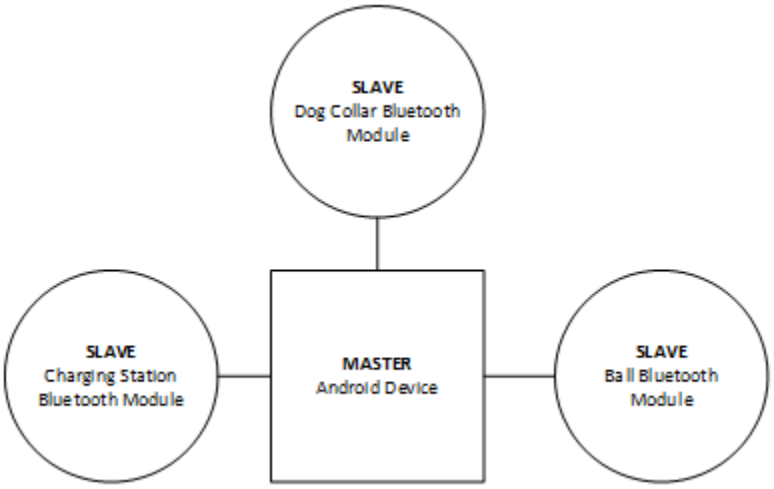

Figure 3.6 Puppy Pal Bluetooth Network

In choosing a specific Bluetooth module, many factors will play a role in a final decision such as cost, operating voltage, size, and the complexity of interfacing the module to the system. Table 3.4 provides a table of significant specifications of potential Bluetooth modules. From observing the table, it appears that all the modules require around the same operating voltage to run, with modules such as the RN-42 with a potential 6 volt operating voltage. The largest module appears to be the HC Bluetooth modules, with the RN-42 and the WT11i being approximately around the same size. Looking at the signal coverage

specification, once again the HC module has the lowest standard in comparison of the other two modules with 30 feet, the RN-42 ranging from 50 to 60 feet, and the WT11i with a significant line of sight range of 328 to 984 feet. The max data rate value for all three potential Bluetooth modules are around the same of around 2 to 3 Mbps, with the HC module with the lowest potential data rate. The HC-05 module will cost the least amount, with the RN-42 and WT11i costing in the 30 dollar range. With all the specifications looked at, the HC module would be the ideal choice of hardware in integrating Bluetooth communication into the system. It would fit in perfect with the system because the 30 feet signal coverage is an acceptable range for the Puppy Pal; the project will operate in a house or room with the user controlling it near the ball, so a 30 feet range is more than acceptable. In addition, the HC module can connect to the Android device in a simple way by locating the module from the Android and entering a given password to connect. The HC module is larger in size in comparison to the other two, but can be negated due to the the price of the HC module being much lower.

Bluetooth Module	**HC (06, 05)**	**RN-42**	**Bluegiga WT11i**
Operating voltage	3.3 V	3.3 to 6 V	2.7 to 3.6 V
Size	4.3 x 1.6 x 0.7 cm	38 x 17 mm	35.75 x 14.5 x 2.6 mm
Baud rate	9600	9600	
Signal coverage	30 ft.	50 to 60 ft.	328 -984 ft. (L.O.S.)
Max Data Rate	2.1 Mbps	3 Mbps	2-3 Mbps
Price	10.00	35.00 to 40.00	30.00
Interfacing Complexity	Simple (Password connectivity)	Mildly complex (requires programming)	Mildly complex (can be integrated with the ATmega328p)

Table 3.4 Bluetooth module comparison

The HC-05 was chosen for wireless communication hardware due to the size, many open source references, and simplicity. In addition, connecting to the module from the Android device will be treated as connecting to any other external device, such as an ear piece for example. Just enter a pin code from the mobile device and then it will auto connect to the Puppy Pal.

3.3.2 System Processing

3.3.2.1 Microcontrollers

MSP430 Launchpad: The MSP430 from Texas Instruments value line is a fantastic processor for the price. When you order the package you get two microprocessors: the msp430G2553IN20 and msp430G2452IN20. They're both identical other than the internal clock speeds, but on the development board you defunct both by soldering the external 32.768kHz crystal onto it. The tools that are available make downloading code onto the chip very easy. The development board's only interface is USB, which provides power and a tunnel to the processors flash memory to burn code in. Some of its more important technical specs are 16kB flash memory, 512B of RAM, interruptible GPIOs, 16-bit timer, 8-channel 10-bit ADC, and support for USCI, I2C and UART serial communications. There are also plenty of booster packs that give the processor some extended features. The processor runs on 3.3 volts and also has configurable low power modes, which would be perfect for our application. The real flaw of this processor is its code space. The processor is part of TIs value line for a reason: it's for hobbyists to tinker around with. There is a code expectancy of at least five times the amount available, so that immediately put this one out of possibilities. Aside from that, there is only one serial communication line. Although this could be dealt with by a little extra effort, coding would be much easier with multiple UART lines, because there will be multiple UART signals coming in at any time. By having only one data line for this, messages would have to have extra details encoded in them, which would in turn have to be decoded on the processor level. Speed is absolutely critical for the Puppy Pal device, so it cannot afford the extra cycles this decoding would bring along. Another area where the MSP430 shines is its community support. Virtually every question about the processor has been asked and answered by TI, and if not on some online forum. There are open source alternatives to Code Composer Studio as well. GCC has a package that supports compiling, linking, and loading of MSP430 programs through the USB interface. There are also plenty of command line tools that allow memory and register dumps of running programs. GCC also provides a C++ compiler, but the limited code space on the chip makes this option impractical. Below is a summary of the pros and cons of the MSP430 Launchpad. Table 3.5 shows a summary of the pros and cons of the MSP430.

Pros	Cheap, great community support, open source alternatives to all software
Cons	Slow speeds, limit flash and RAM memory, C++ isn't practical, limited serial communications

Table 3.5 Summary of MSP430 pros and cons

ATmega328P: The ATmega328P comes from Atmel corporation and has many useful features for the Puppy Pal device. As far as its physical size, the processor is quite small, with dimensions of about a square half-inch. It has 24 GPIO pins, and 8 more dedicated to specific features, two being a two-line UART interface. One of its best features is that it runs on 1.5 - 5.5 volts. This comes in perfect for low power modes which the Puppy Pal device heavily takes advantage of. All 24 of the GPIO pins are interruptible which is nice, but a bit overkill. It has 30kB of flash memory, 2kB SRAM and 1024B of EEPROM. Much like the MSP430, the memory statistics just aren't enough for our code. Furthermore, the community support and 3rd party tools are slim to none with this device. With the time constraints we are facing, the overhead of not being able to find exactly what we need in the case of an emergency turned this part away. Last, and probably most detrimental, is that the processor is part of the AVR 8-bit series. Because Puppy Pal is going to be very math intensive, 8-bits for calculations would not cut it. Although clever techniques allow complex computations to be done with 8-bit devices, there were better processors for similar prices out there. Table 3.6 shows a summary of the pros and cons of the ATmega328P.

Pros	Cheap, plenty of interruptible pins, operating voltage of as low as 1.5V
Cons	Slow speeds, 30kB flash, 2kB RAM, poor community support, only 8-bit

Table 3.6 Summary of ATmega328P pros and cons

LPC2148: The last microcontroller we considered was the LPC2148 by Philips. This is as beefy as a processor can get for small embedded system. It's part of the ARM architecture suite, and offers a 32-bit RISC instructions set. The chip is physically small and powerful, with tons of features including but not limited to 512kB of flash, 32kB of RAM, 2 10-but ADCs with 14 channels a piece, a full speed USB 2.0 Speed Device Controller, 2 UART, I2C and SPI interfaces, a PWM unit, and a 60mHz processor with an on-board crystal oscillator to top it all off. All of these features are perfect for the Puppy Pal device: plenty of code size, plenty of RAM, two UART channels, and a PWM unit. The PWM unit comes in especially handy because of the constant change to our duty cycle to get the wheels to spin at certain rates. Aside from the Hardware, there is decent community support and a very detailed users guide that goes over all of the features the Puppy Pal device will use. It comes standard with a C and C++ compiler, and because of the flash size, for the software running on the device many useful features of the C++ language can be taken advantage of, like operator overloading and virtual function tables. The processors main interface to embed code is through I2C. There are also no development tools available that make the process of writing, compiler and loading easy. This is also a processor for very large-end embedded systems. In other words, there are many peripherals this processor is designed to handle, like external memory and network interfaces. Though it doesn't really harm anything on the Puppy Pal device, it would be that much more overhead to disable all the features that

weren't go to be used. This package is nearly flawless other than that, and the only reason it was not chosen is because it was unfamiliar territory compared to the last option. Table 3.7 shows a summary of the pros and cons of the LPC2148.

Pros	Cheap, 512kB flash, PWN unit, C++ support, 60mHz
Cons	Unfamiliar territory, extra unneeded peripherals

Table 3.7 Summary of LPC2148 pros and cons

TMS320F28069MPN: TI has quite a few options for microprocessors. Even more so, there different lines of processors have different options you can filter out to get exactly what you're looking for. In doing so, the TMS320F28069MPN from the C2000 series was found. For roughly the same price as the LPC2148, this 32-bit processor comes with a 90Mhz master clock frequency which will come in very handy for transferring, receiving and decoding messages. There is also Control Law Accelerator that supports 32-bit floating point operations that are done independently of the main CPU. In addition to those features it contains 256kB of flash, 96kB of RAM and 2kB of OTP ROM. This processor runs on 3.3V and comes with two different types of low power modes that can be used for when the Puppy Pal device is in either its charging or waiting state. Some other useful features are a Peripheral Interrupt Expansion block that supports interrupts on all peripherals, 3 32-bit timers, 8 pulse width modulation units, 16 channels of 12-bit ADC with a conversion time if 286 nanoseconds, 2 UART and SPI modules, and 40 GPIO pins with input filtering. Aside from reliability, Texas Instruments products are also known for their great documentation and community support. The C2000 series is no exception. Their website is full of example code and schematics to ease the processes of design for common products. One of the nicest features of the C2000 series is the inclusion of the instaSPIN modules. This is a library of products that aid in embedded system motor controlling. The software is specifically for controlling devices from a computer and not to be run directly on the embedded system so it cannot be used for the final product, but it will be incredibly helpful for the early stages of development when simple testing of the two motors needs to be done. There are plenty of breakout boards for this chip as well. The development platform most commonly used for this product is Code Composer Studio. It has version for both Windows and Linux and interfaces nicely with development board. It handles all compiling, linking and downloading of code to the board. It has full support for C++, and because of the code space on the chip all of its features can be utilized. Much like the LPC2148, the chip also comes with a lot of extra peripherals that will not be used. For instance, the I2C interface will have no use and just be an extra pin on the board, but this is much like 35 of 40 other GPIOs that will not be used. This is a true embedded processor, so the hassle of disable features in code is not a problem; if they're not needed they will just not be used, unlike in the Philips alternative. Table 3.8 shows a summary of the pros and cons of the TMS320F28069MPN.

Pros	Cheap, 256kB flash, 96kB ROM, PWN units, full and code-efficient C++ support, 90mHz, great community support, familiar territory for all members, 2 UART lines, instaSPIN technology
Cons	Extra unneeded peripherals

Table 3.8 Summary of TMS320F28069MPN pros and cons

3.3.2.2 FPGA

FPGAs are another alternative to a pure microcontroller project. Although FPGAs are not typically used for projects like this, they do carry some advantages to them that would prove to be useful for the Puppy Pal device. For one, FPGAs focus on concurrency. This would give us much more precision on our ISRs because we could get into detail about how long they should take. With that being said however, the code design currently only has one statement executing in our ISR so this doesn't help us out much. Secondly, FPGAs are extremely flexible, but this comes at a hefty cost. You have the unique ability to create virtually any platform you want with these devices, but the overhead of having to create them is not worth it for this project. When talking about microcontrollers, the hard part of choosing a chip is sorting through all of the different options that each provides. The ability to add and remove features as needed provides a huge advantage when working with FPGA. Unfortunately, you must use a HDL to go about doing this. Another consequence of FPGAs is that they consume much more power than microcontrollers, and there are typically no optional low power modes to choose from. Furthermore, FPGAs do not handle serial communications as well as microcontrollers. Serial communications is one of the most vital operations of the Puppy Pal and could not function without it. FPGAs are a great option for many projects, but in the case of small embedded systems the overhead they come with is not worth the risk.

3.3.3 Motors and Actuators

Mobility and maneuverability are two of Puppy Pal's features. Motors are required to initiate movement and to choose the direction the device will go. The types of motors chosen will meet the needs of the mechanical design without hindering speed, steering, or power. The actuators used would also meet these criteria.

3.3.3.1 DC Motors

A DC power supply is the most practical source for this project. This means the use of DC motors are preferable to AC. They use less power and would not require the project to be connected to a power outlet at all times.

Brush DC Motor: A brush DC motor is cheap and simple. The simplicity almost makes a control system redundant. Since the design of an accurate control system is one of the goals of this project, a brush motor would allow the design of a modest feedback and control system. However, a feedback system was abandoned to make time to actually build and test the mechanical system. A brush DC motor is likely to wear out over time. Although it is unlikely to be used so often that this problem arises before the end of the prototype period, the 3V motors used while testing the motor driver stopped operating at peak performance only 2 weeks before the final deadline. The test motors were replaced with the 6V motors intended for long-term use at this point. It was also very likely that the parts used would be second-hand, so the chance of worn-out brushes was a distinct possibility. These second-hand motors were used in the construction in testing process instead of the final model to get the most use out of the cheaper parts. Brushed motors also come with the danger of sparks and electrical noise. Another issue was the heat of the motor after prolonged use. The enclosure did not allow the efficient escape of heat from inside of Puppy Pal. This could have resulted in the device not operating correctly or components overheating. A temperature sensor could have been included in the to counteract this issue. A certain temperature would tell Puppy Pal to go into standby mode and wait for the temperature to drop before becoming active again. After several tests, a temperature sensor was considered redundant because the overheating of the motors could be observed with a multimeter and from the distinct smell of burning plastic.

Brushless DC Motor: The more expensive brushless DC motor would be a better choice in this project. There wouldn't be the required maintenance of brushes involved. The lack of brushes also eliminates the risk of sparking, although electrical noise would still be an issue to contend with. The nature of this type of motor allows precise control over speed. Precision would require the design of a complex feedback control system.

3.3.3.2 AC Motor

An AC motor is driven by an AC power source. Puppy Pal uses DC batteries. Using AC motors would have meant the addition of an AC power supply. The AC power supply most readily available was a wall outlet. This would mean keeping Puppy Pal connected to a wall outlet. This signal would then need to go through a step down transformer to power the motor. Although the circuit design would be simple, a wire coming out of the toy is cumbersome; the wire limits Puppy Pal's range of motion and its overall autonomy. The wire is also another object a dog could decide to play with, which could result in serious injury. To avoid such complications and dangers, AC motors were not be part of this project.

3.3.3.3 Servo Motor

Servo motors are used to guide rotational motion. They are typically packaged with a control circuit and a motor. This could have allowed for simple incorporation into the design of Puppy Pal. However, the mechanical system used did not require a servo motor for steering or leave enough physical space inside of the enclosure for the entire package.

3.3.3.4 Linear Actuators

A pair of linear actuators could have been used in the mechanical system. Weights attached to the actuators would move along with them depending on the direction chosen. As the actuator shifts in one direction, the center of gravity changes and Puppy Pal goes in this new direction. The issue with this motor was the location of the actuators and the complicated nature of the control system that would have to be designed. There is also the problem of how mounting the actuators and preventing them from colliding with each other and other parts.

3.3.4 Sound System Techniques

Sound projection hardware will need to output a sound wave that will potentially lure the dog towards the system. The method on how the sound will be played will be dependent on many factors that may be technical or not. A non-technical factor that may be used in determining a way to choose a method will be space, some sound projecting methods require a significant amount of circuitry, and it would be in the project's best interest to stay away from implementing a method that will require a large amount of space. In addition, a technical factor that may play a role in choosing a method will be how much current the hardware will draw to the system. A low impedance sound system may draw too much current for the hardware to be implemented with the MCU. To conclude, a method that requires the least amount of space in hardware and draw the least amount of current will be the best approach in choosing hardware in integrating a sound system.

3.3.4.1 MP3 Shield with 8 Ohm Speaker

Connecting an 8 ohm speaker directly to an output pin from the MCU could draw too much current to the system, under extreme conditions potentially destroying the pin and adding a resistor above 120 Ohms will not output a high quality sound from the speaker. An MP3 shield of some sort can be used with a small eight ohm speaker to output sound from the Puppy Pal. If using an ATmega328P

MCU, the Arduino MP3 shield can be potentially be used. The shield has an UART interface with an audio amplifier embedded on the board to drive a 3 watt speaker, and a volume control functionality. The shield reads in an audio file from an SD card or USB flash drive in MP3 or WAV format. If the user does not want an external storage device connected at all times, there is a built in SPI flash memory to save audio files from the SD card/flash drive to the shield [9]. Figure 3.7 illustrates a block diagram of integrating a sound system using an MP3 shield. The shield is programmed from the main MCU, so control functionalities and input/output pins are set through the Arduino IDE software. The benefits of using this design will give the user a choice of what sound is being played from the device and multiple sounds can be played. The cons of implementing this system is, in comparison to using a piezoelectric transducer, it would be more a more expensive alternative. In addition, this method would require far more space, as the Puppy Pal will be designed to be in a small 6 inch spherical enclosure. Also, multiple audio files are not needed, since the device will be designated to be used with dogs, a short sound clip or a basic impulse sound would suffice under ideal circumstances in sound system applications.

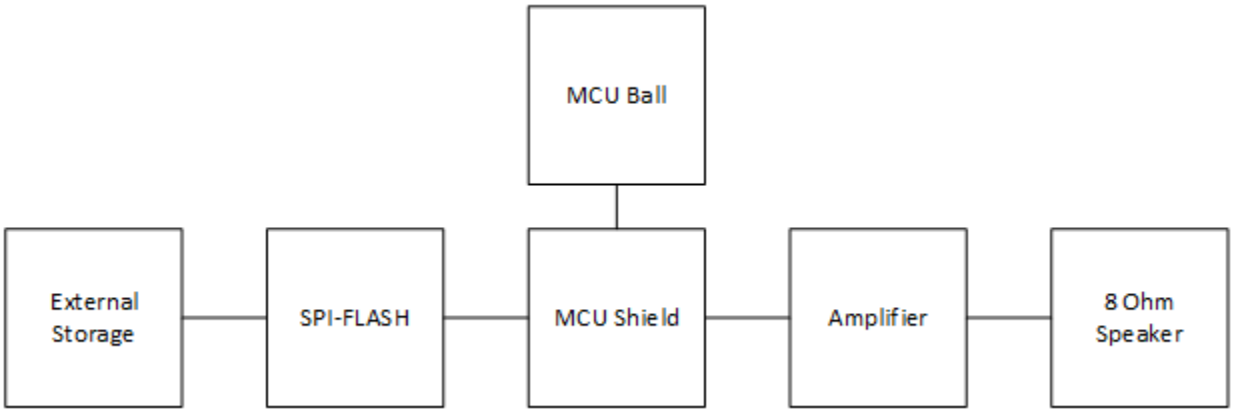

Figure 3.7 Block diagram of sound system using MP3 shield

3.3.4.2 Piezoelectric Sound Generator

Piezoelectric sound generators can be potentially implemented into the system, more specifically inside the ball. Piezoelectric sound generators output a sound that can be in a minimal frequency range, such as warning signals or beeping/buzzing sounds heard in many household appliances. They range from having a petit sound output to a rough noisy sound output. There are two types of piezoelectric sound generators that can be looked at: piezoelectric transducers and piezoelectric buzzers. Piezoelectric transducers are implemented with an oscillating circuit and as for buzzers are designed to have an internal oscillating circuit embedded within the component [10]. Piezoelectric sound generating circuits are completely dynamic and robust, which will be useful since the device will be designed for a high durability factor. In addition they are fairly cost and

power efficient, with an operating voltage range from 3 to 12 volts. The size also plays a significant role, as piezoelectric sound generators are usually small to add on to the system and will be a beneficial factor to look at when trying to choose a method to fit inside a 6 inch enclosure. Table 3.9 provides information on potential piezoelectric sound generators that may be used.

Part	CSPT11A05	CSPT23C09-3.2	CSPB15A05-4.0	CPB40A09
Type	Transducer	Transducer	Buzzer	Buzzer
Size (mm)	11x9x1.7	23x22	11x9.5x8	40x20
Rated Voltage (V)	5	9	5	9
Operating Voltage (V)	1-20	1-30	3-16	3-20
Max Rated Current (mA)	1	5	8	50
Sound Output (dB)	73	102	85	100

Table 3.9 Table of Piezoelectric sound generator specifications

3.3.4.3 Electronic Dog Whistle Circuit

It is a common concept studied that dogs can hear sounds at higher frequencies in comparison to a human. A human can hear at a frequency range approximately between 64 to 23,000 Hz and dogs can hear at a frequency range approximately between 67 to 45,000 Hz. So basing of those frequency ranges, frequencies higher than 23,000 Hz can barely be heard from humans but can be sensitive to a dog. A typical dog whistle is in the frequency range between 20 to 54 kHz. An electronic dog whistle can potentially be implemented into the system by using a design that can provide the higher frequency, as shown in Figure 3.8 created by Popescu Marian [11]. The circuit uses a piezoelectric transducer to supply the output sound, in this case a high frequency sound to imitate a dog whistle. It uses a transducer because it is driven by an external oscillating circuit. The circuit also requires four transistors for signal amplification and six inverters. The components to the left, which are the three inverters, the resistor, and the capacitor all serve as an oscillation function which produces a square wave signal. The purpose of generating a square wave is to reduce current needed. The circuit requires 9 volts to be powered and generates an output frequency of about 21 kHz. The push button can be replaced by a MOSFET transistor; the gate can be hooked up to MCU output so it doesn't draw a significant amount of current. So if the MCU output is high, current supplied from the 9 volt source will run through the circuit and then trigger the piezoelectric transducer.

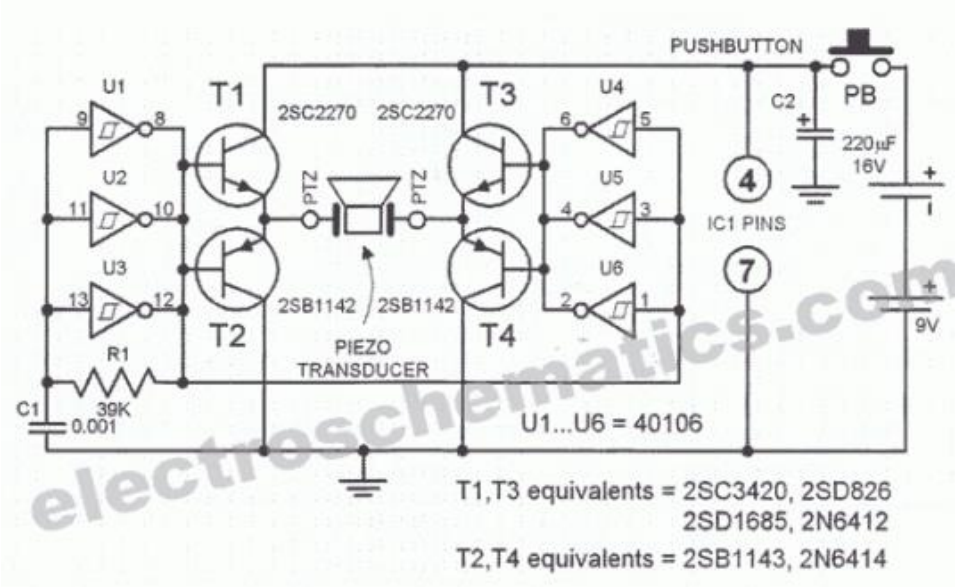

Figure 3.8 Electronic Whistle Dog Schematic

Another potential dog whistle circuit can be implemented using a 555 timer and an 82 dB piezoelectric transducer like the circuit designed by Tomaz Lazar, as displayed in Figure 3.9 [12]. The circuit is a basic design and requires a low number of components. The circuit is powered by a 9 volt source and generated frequency is dependent on the values of the potentiometer that will be used. The potentiometer reflects on pitch frequency; a lower resistance generates a higher frequency and a higher resistance generates a lower frequency. If a dog whistle is implemented on to the system, this design would appear to provide the best approach. The design does not take up as much space as the design above and also does not require a significant amount of hardware. Similar to the previous design, a transistor can replace the mechanical button, where the gate of the transistor is connected to the MCU with the source and drain being connected to be between the voltage source and 555 timer. A note to conclude on is that the dog will not automatically react to a dog whistle, it will need to be trained to react to the sound, if not trained the dog will most likely not react. This concept will probably be accurate for most sounds that may be chosen.

3.3.4.4 Sound Subsystem

The sound subsystem will provide a sound output to gain the attention of the dog. To operate a sound output, a system will need to be connected to the MCU to trigger the sound subsystem to turn on. The approach to designing the sound system will use the 555 timer with a piezoelectric sound generator, more specifically a piezoelectric transducer or buzzer. The performance of the transducer will be dependent on the potentiometer value, testing for optimal conditions will provide the best resistor value. The sound subsystem will require low power applications to limit a high current value from entering the MCU output pin.

The design will primarily focus around the 555 timer and the piezoelectric sound generator. The design does not require a ton of hardware components, other than a couple of resistors, capacitors, and is power supply. The system is powered by a 9 volt battery which can be gained from the 12 volt battery using a voltage regulator. Since the project will use a 5 volt output from the MCU pin, a op-amp will be interfaced as a switching function. The op-amp will provide amplification of the MCU output voltage to be used to turn on the sound system. Table 3.10 displays a table providing the hardware components that will be needed.

Component	Value/Type	Quantity
Op-Amp	Low Power	1
Resistor(s) (Ohms)	4 k, 1k, 800 , 1000,	2
Capacitor(s)	10 nF, 10 uF	2
555 Timer	NE555	1
12V Power Supply	DC Power	1
Potentiometer	Will vary	1
Piezoelectric Buzzer	82 dB (5-9 volts)	1

Table 3.10 Table of sound system required hardware.

As displayed in the schematic in Figure 3.9 located in section 3.3.4.1, the design uses a mechanical switch to turn on the system, since the Puppy Pal will be using a MCU for turning on the sound subsystem design, an op-amp will be used. An op-amp will be used for many reasons, one reason is for low current applications. It is an important protocol that the MCU will not be introduced to a dangerous amount of current. This is possible because a typical op-amp has a high input impedance. Figure 3.9 illustrates the design of the switch that will need to be used to turn on the sound system. The Vcc pin will be connected to the main power source, in this case the positive 12 volts to +Vcc and negative 12 Volts to -Vcc. When the LOW voltage is amplified (when the MCU output voltage is 0 volts), an extremely low voltage that is negligible will be at the output of the op-amp, which will be too low to turn on the sound subsystem. More specifically the op-amp will be configured in the non-inverting amplifying mode. To amplify the 5 volt input to around 9 volts to trigger the sound system, the op-amp switching circuit will need to be configured a specific way. To configure the circuit, it is important to choose the correct values of resistors to output a 9 volt nominal voltage to turn on the 555 timer. The range of around 9-12 volts is needed for optimal operation. When the op-circuit is configured in the non-inverting mode, the following equation can be used to determine the ratio of resistors.

$$\frac{V_{out}}{V_{MCU}} = \left(\frac{R_1}{R_2} + 1\right) = \frac{9.0}{5.0} = \left(\frac{R_1}{R_2} + 1\right)$$

$$\frac{R_1}{R_2} = 0.8$$

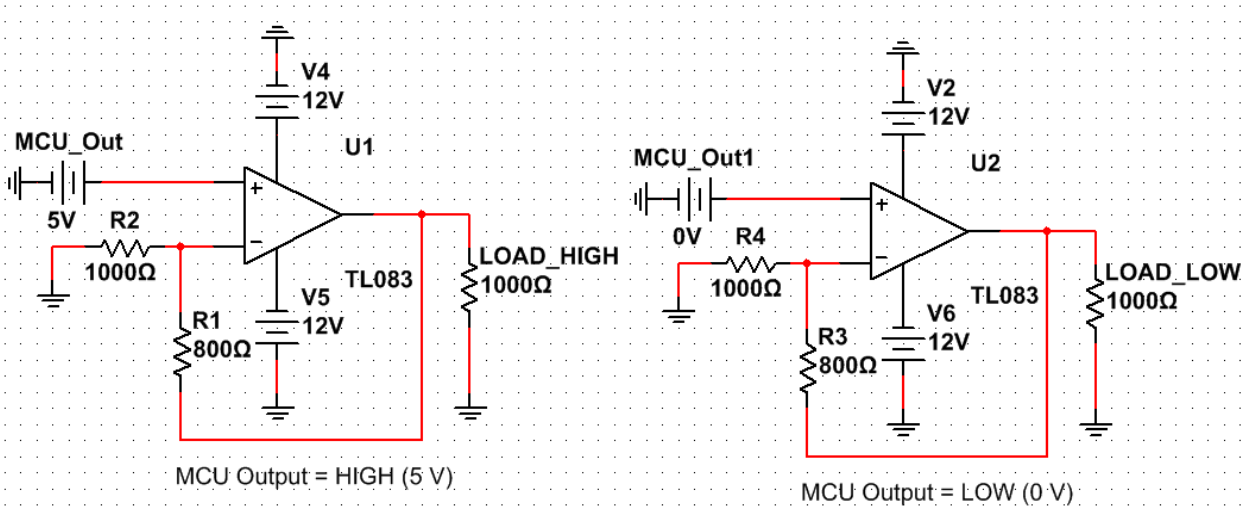

Figure 3.9 Multisim schematic displaying the switch that will turn on the sound projection hardware.

Table 3.11 provides simulation results of load current, load voltage, and input current when the input voltage is either HIGH (5 V) or LOW (0 V). For this simulation, the load resistance of 500 Ohms is used, it is noted that load impedance will change depending on what type of components are being used, so the input resistors will be chosen accordingly.

Voltage from MCU	Load Current	Load Voltage	MCU Current
HIGH	17.836 mA	9 V	0 A
LOW	0 A	0 V	0 A

Table 3.11 Switch simulation results

From simulation results, it can be observed that using an op-amp as an ON/OFF switching application behaves almost identically as a mechanical switch, as a switching function is purely dependent on the output voltage from the MCU. In the simplest description, if the Puppy Pal is in autonomous mode the motion detection system that is measuring the dog's movement will trigger the non-inverting terminal to be high, which is 5 volts. If the Puppy Pal is in remote control mode, the non-inverting input voltage will be triggered by the user. For example, the user will send a specific character from the phone to the MCU. Then the MCU will set the pin connected to the pin of the non-inverting terminal to the HIGH voltage.

The schematic below in Figure displays the dog whistle circuit using the switch developed in the previous section instead of the mechanical push button. The important components that should be observed are whether the MCU output is either HIGH or LOW, the configuration value of the 4700 Ohm potentiometer, and how much current will be delivered to the MCU pin. Basically how the circuit functions is if the MCU output is LOW (0 volts), a negligible low voltage will be fed into the 555 timer, and will not cause any sort of oscillation to generate a square wave to output an adequate frequency. However if MCU output is HIGH (5 volts), the 5 volts will be amplified to generate a 9 volt input to the sound subsystem, which is the nominal value of operation. In theory, this will cause a high frequency signal to be generated at the output across the load, the 1000 Ohm resistor. The 1000 Ohm resistor represents the load of an 82 dB piezoelectric buzzer.

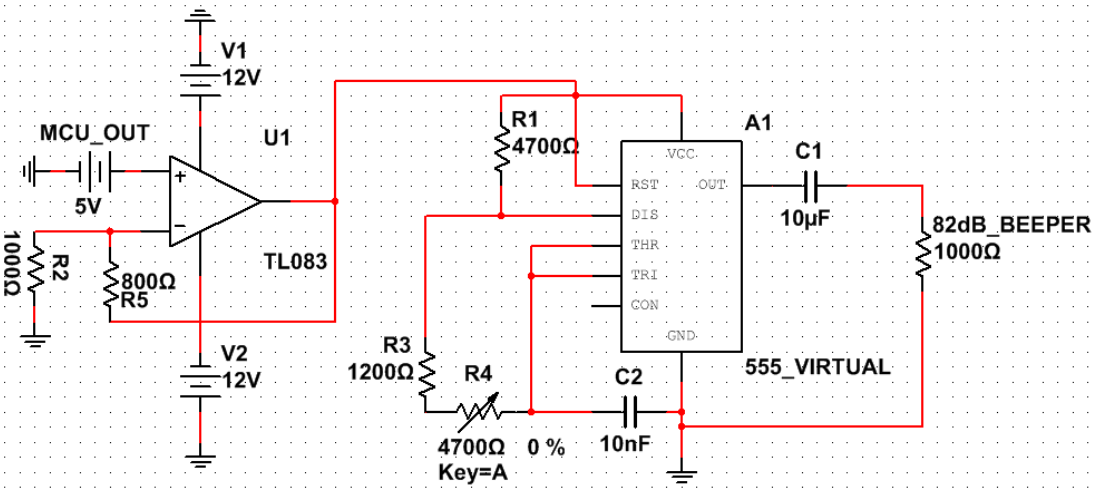

Figure 3.10 Schematic of dog whistle circuit.

The aim will be to get an output frequency on 30 to 50 kHz, since those are the typical ranges for dog whistles. Table 3.12 displays the dog whistle circuit simulation results under different potentiometer values. It can be observed from the table, that the lower the potentiometer value the higher the frequency, however other parameters may be significant in choosing the correct value like as in the ratings of the 82 dB piezoelectric buzzer. Since an op-amp will be used as the switching function, due to the high input impedance, a dangerous amount of current will not be able to come into contact with the MCU output pin.

Potentiometer Value (4700 Ohm)	MCU Voltage (HIGH-5 V, LOW- 0 V)	Output Frequency (Hz)
100 %	HIGH	8645.13
80 %	HIGH	9571.39
70 %	HIGH	10309.2
60 %	HIGH	11173.18
50 %	HIGH	12048.19
40 %	HIGH	13073
30 %	HIGH	13922.14
20%	HIGH	15765.41
10%	HIGH	17866.71
0 %	HIGH	19490.89
0 %	LOW	0.00

Table 3.12 Dog whistle circuit simulation results

Figure 3.11 illustrates a frequency plot with respect to the potentiometer value. Observing the data from the table above, it is noted that the plot based off the assumptions that the value from the potentiometer value is inversely proportional to the output frequency. When the MCU voltage is LOW, the circuit will never generate a frequency even if the potentiometer is configured for optimal results.

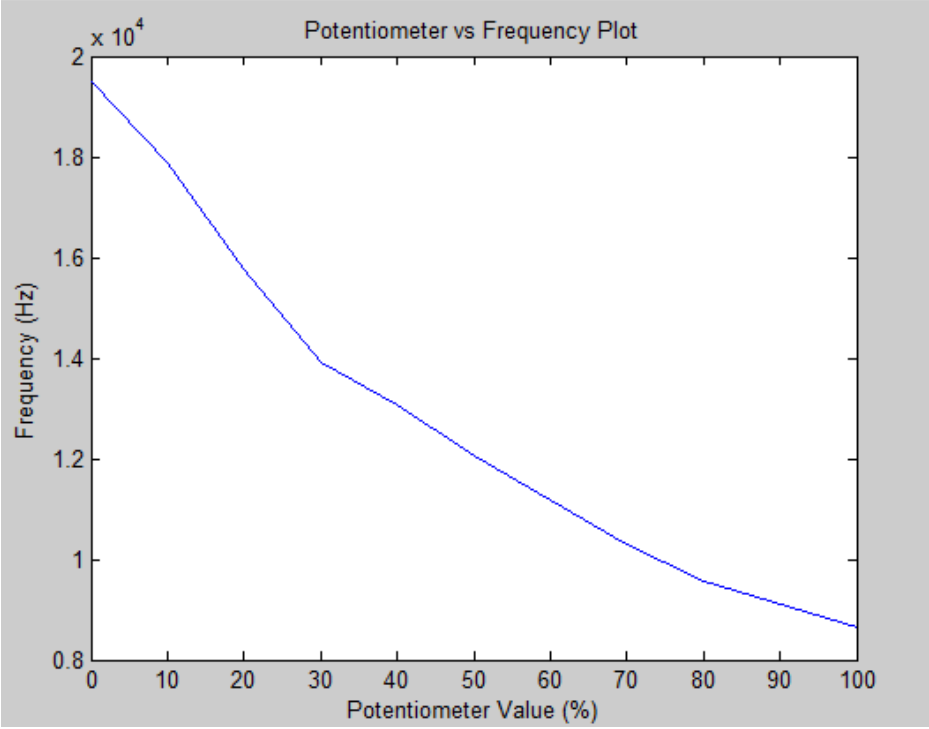

Figure 3.11 Dog whistle circuit simulation results

The sound system test will test different aspects of the design that was described in previous sections, such as input current, output current, and output frequency

at an optimal potentiometer value. Multiple potentiometer values will be tested in order to determine optimal sound output as well.

The switch test will test if the switch design using a non-inverting op-amp will function correctly. To test there will be two different sources that will be used for the 5 volt turn on voltage, one will be from a DC power supply and the other will be from the MCU output pin. A 12 volt battery or 12 volts from the DC power supply will be used for Vcc pins on the op-amp. To confirm if the switch is functioning correctly, when a 5 volt is applied at the input there will be a 9 volt output. Table 3.13 displays the results of the switch test.

Voltage	Vout (Simulation)	Vout (Expected)
5 V (Power Supply)	9 V	8.93 V
5 V (MCU)	9 V	8.84 V
0 V	0 V	0.033 mV

Table 3.13 Switch test results

Testing will be done to configure the best resistor value that will be used to provide the most optimal frequency. The frequency that would be ideal would be around 20 to 22 kHz. To test the circuit, select a specific resistor value that represents the potentiometer on the schematic, set the input to 5 volts, and then measure the output signal using an oscilloscope. The potentiometer-frequency test results are displayed below. Using test results will provide the most adequate resistor to be selected. Table 3.14 shows the expectations for the test results.

Potentiometer Value (%)	0	10	20	30	40	50	60	70	80	90	100
Output Frequency (kHz)(Expected)	25	23	21	20	19	18	16	15	13	11	10

Table 3.14

3.3.5 Battery

Two battery packs were required for this project, one to power the collar worn by the dog and one to power Puppy Pal. Both batteries have size constraints imposed by the mechanical housing of their respective systems, and both had to handle impacts caused by play safely and without failure or disconnecting. The batteries were chosen to be of similar nominal voltage to the subsystem with the highest power requirement in order to minimize losses encountered by voltage regulation.

3.3.5.1 Collar Battery

The primary driving factors for selecting the collar battery are a voltage within the range of 1.9V and 3.9V, safety, wide availability, cost, capacity, self-discharge current, and size. The dog collar will use primary (non-rechargeable) batteries because the collar should not have to be regularly removed to recharge, should have no external openings to promote a water resistant design, and a wireless charging system would be too large. Typical dog collars measure approximately 1 inch (25mm) wide, and in the interest of comfort and aesthetics the enclosure should be of similar width. The batteries will have to be situated side by side within an enclosure and will require connectors, so the width of one battery should be under 12mm. AAA batteries have a maximum diameter of 10.5mm which AA batteries measure to 14.5mm, and when the extra size of an enclosure is added, the AA batteries are too large. For this design, two Duracell Coppertop AAA batteries will be used, however, they may be replaced with any similar AAA battery operating at a nominal 1.5V per cell. In interest of safety, these batteries will be monitored by a temperature sensor and voltage sensor to ensure no thresholds are exceeded.

3.3.5.2 Puppy Pal Battery

The most important parameters for the selection of Puppy Pal's battery are nominal voltage, safety, size, weight, cost, peak current, charging complexity, and capacity. The table shown in Figure 3.12 was found to be helpful in selecting the proper battery chemistry for this design, based on the most important design criteria. The nominal voltage of this system will be 12V, which fits well with nickel metal hydride (NiMH), nickel cadmium (NiCd), and lead acid batteries which all have cell voltages that can be combined in series to provide a nominal 12V, however, a voltage regulator could be used to obtain the needed voltage if the benefits of another chemistry outweigh the drawbacks of adding a regulator. It is possible that a regulator may still be required due to the change in voltage that batteries experience under changing load conditions. Lithium based chemistries, particularly lithium-ioin and lithium-ion polymer, have the highest energy density, but NiMH is also likely to be high enough for this project with respect to both energy to mass and energy to volume, making NiMH the simplest choice if it meets the battery life requirements. The energy densities of lithium based chemistries are greater in terms of volume and approximately double with respect to mass, making them a viable option if more power is needed. Issues with using any lithium based battery chemistry are that shipping regulations exist and become more problematic when using larger batteries. The primary downfall of NiMH batteries is that they have a higher self-discharge rate than many other chemistries and performance will degrade without maintenance, which could cause potential problems if the device is permanently sealed. NiMH and all lithium based chemistries require specialized circuits to charge and lithium based also require a specialized protection circuit to keep voltage and current within

safe levels. The price of these batteries vary greatly depending on chemistry, capacity, and maximum charge and discharge ratings. In general, lithium based chemistries are most expensive per amp-hour followed by NiMH, NiCd and lead acid [13]. A NiMH battery will be used in the design stage with the option to switch to a higher density and higher cost lithium based chemistry with a voltage regulator if the need arises.

	NiCd	NiMH	Lead Acid	Li-ion	Li-ion polymer	Reusable Alkaline
Gravimetric Energy Density (Wh/kg)	45-80	60-120	30-50	110-160	100-130	80 (initial)
Internal Resistance (includes peripheral circuits) in mΩ	100 to 200[1] 6V pack	200 to 300[1] 6V pack	<100[1] 12V pack	150 to 250[1] 7.2V pack	200 to 300[1] 7.2V pack	200 to 2000[1] 6V pack
Cycle Life (to 80% of initial capacity)	1500[2]	300 to 500[2,3]	200 to 300[2]	500 to 1000[3]	300 to 500	50[3] (to 50%)
Fast Charge Time	1h typical	2-4h	8-16h	2-4h	2-4h	2-3h
Overcharge Tolerance	moderate	low	high	very low	low	moderate
Self-discharge / Month (room temperature)	20%[4]	30%[4]	5%	10%[5]	~10%[5]	0.3%
Cell Voltage (nominal)	1.25V[6]	1.25V[6]	2V	3.6V	3.6V	1.5V
Load Current						
- peak	20C	5C	5C[7]	>2C	>2C	0.5C
- best result	1C	0.5C or lower	0.2C	1C or lower	1C or lower	0.2C or lower
Operating Temperature (discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C	0 to 65°C
Maintenance Requirement	30 to 60 days	60 to 90 days	3 to 6 months[9]	not req.	not req.	not req.
Typical Battery Cost (US$, reference only)	$50 (7.2V)	$60 (7.2V)	$25 (6V)	$100 (7.2V)	$100 (7.2V)	$5 (9V)
Cost per Cycle (US$)[11]	$0.04	$0.12	$0.10	$0.14	$0.29	$0.10-0.50
Commercial use since	1950	1990	1970	1991	1999	1992

Figure 3.12 Batter chemistry comparison, showing benefits and drawbacks of common battery chemistries, from Battery University [13] (permission requested).

3.3.5.3 State of Charge

One of Puppy Pal's initial features is the ability to return to its charging station when power is low. To do so, the state of charge in its battery had to be measured. This value would be used by the microcontroller to decide when to return to the base and charge. A great challenge was accurately measuring the state of charge. Determining the amount of charge left while the battery is discharging is, at best, an estimate. In general, a battery's maximum charge decreases with age. As a result, what was considered an 80% charge when the battery was new could be considered a 100% charge after a year of use or idle storage. If this feature had come to fruition, the group would have to take this possibility into account, possibly going through recalibration each time the battery is charged. Different methods can be used together to find the approximate battery life. For NiMH batteries, measuring current and integrating it is a valid option [14]. The downside of this method is that current is not drained at a constant rate while Puppy Pal is active. The motors driving the toy will not always consume current at the same rate. Although pulse width modulation can change the draw of current from a constantly fluctuating amount into a nearly constant signal, the actual use of Puppy Pal will not be the same each day. In addition, this method works best when the battery has been charged completely after having been fully drained. If the amount of current used to charge the battery to 100% is known, then the amount of current needed to drain the battery can be estimated. To do so, a current sensor would have beed needed to measure the current going into and leaving Puppy Pal's battery pack during charging and discharging, respectively. Before a specific sensor can be selected, the range of current of the battery pack would have to be determined.

3.3.6 Motion Detection

The motion detection subsystem will be composed of two individual subsystems, one for determining when the dog is awake and one for determining when the dog is within Puppy Pal's area of play. The two independent subsystems will provide the ball with individual signals and will allow decisions to be made based on whether the dog is awake, in the play area, or both.

The subsystem for determining when a dog is within the range of play will be located on the base charging station, because it is defined as the center of the area of play. Many methods exist for sensing the proximity of an object, and examples can be seen every day when walking past an automatic light. Systems of this type often use Passive Infrared (PIR) sensors to detect the thermal radiation produced by all objects at temperatures greater than zero Kelvin. These systems are capable of determining when an object in a specific range of temperatures moves through the field of view, by measuring the difference and rate of change between the current Infrared (IR) radiation level and a previous level [16]. Increasing the number of locations the IR radiation level is measured is

similar to increasing the number of pixels on a screen, and will result in a more sensitive system. Since this type of system is designed filter out average temperature, and detect rapid changes in IR radiation levels, it is capable of functioning in full view of the sun as well as indoors [16]. Other systems of similar nature such as sonar, using ultrasonic sound in place of IR radiation and radar, using radio frequency electromagnetic radiation in place of IR radiation, also function similarly. The drawbacks of using sonar and radar devices is that they are typically active systems because there is no easily discernible sound or radio signal that is unique to all objects that must be detected, as is the case in IR applications. Active systems will require more power in general because the detected signal must also be transmitted, as opposed to passive, in which the signal must only be detected. In addition to the drawbacks of active systems, dogs can hear higher frequency tones than humans, and could potentially hear the ultrasonic sensor, which may be stressful or an annoyance. For these reasons, this design will attempt to use a PIR sensor as the proximity sensor.

The simplest choice for a wearable motion detection system is an accelerometer. An accelerometer can translate mechanical movement into an electrical signal proportional to the strength of the motion. This electrical signal can be communicated to external devices in many ways, but the most common are as an analog voltage, or a serial communication protocol where the value of each byte is proportional to a sample of the analog voltage produced. Depending on the communications system used, one method may be more useful than another, and will be a factor in choosing the accelerometer used in the prototype. The requirement that this subsystem be capable of differentiating between a dog that is sleeping and a dog that is awake poses a problem because dogs, like people, tend to toss and turn while they are sleeping. During motions like this, it is difficult to establish a threshold that can determine a difference between waking motion and sleeping motion. One option for determining the difference could be to impose a time and magnitude constraint, so that a temporary movement would not disturb the system. Issues could arise with different dogs making varying levels while sleeping and while awake, for instance old dogs wake up and slowly rise, where a puppy may jump up from sleep just to curl right back up a few feet away. The best way to account for these differences is by integrating the acceleration data twice, to produce position data [17]. Many dogs make varying levels of motion while sleeping, but no normal dogs move quickly across a room while sleeping. Using the position signal will still require the use of a magnitude and time signal in order to account for accumulating errors that lead to drift, due to noise from the accelerometer and sampling process being compounded during integration. Drift due to accumulation errors during integration also necessitates that this measurement of position should only be stored for comparison for short periods of time and then discarded. Software solutions to minimize this error accumulation exist, but over an extended period of time even the smallest errors grow quickly due to the integration [17]. In order to save power, integration only needs to occur when uncertainty occurs, when there is no large acceleration, no

movement is occurring, but when a large acceleration occurs, integration to position will provide more clarity.

3.3.7 Location Detection

3.3.7.1 Global Positioning System

Use of Global Positioning System (GPS) has the advantage of being available anywhere in the world, with reasonable accuracy and high reliability. The GPS Standard Positioning Service, meaning no augmentation has been used, specifies that the worst case accuracy is 7.8 meters with 95% confidence [18]. The major disadvantage of GPS is that performance degrades as less of the sky is viewable, meaning performance in buildings or around tall buildings suffers. GPS requires a small amount of additional hardware, which will is available as a single module. GPS systems use a common standard for providing data, defined by the National Marine Electronics Association (NMEA) in the NMEA 0183 standard. This standard implements communication between a receiver and a satellite using a string of data, called a sentence, sent using ASCII characters at 4800 bits per second, containing no more than 82 characters, and ending with a checksum for data verification. The format of the sentence a starting character ($), followed by a 5 character identifier string beginning with the letters GP for standard strings and P for proprietary strings followed by the message type for the remaining characters and ending with a comma. The actual message begins after this comma and contains data separated by commas. The last data field is followed by an optional checksum field containing an asterisk and a two digit hexadecimal checksum value, but the final character is always the new line character. This design will require 3 parameters from the GPS system: position, time, and velocity. Position and time will be taken from the $GPGGA string, and velocity will be taken from $GPVTG string. The format for the time field is hours, minutes and seconds concatenated as a single number and the time zone is UTC. The format of the position field will be two values for latitude, degrees and minutes concatenated to a single five digit value with three decimal points of precision and a single character for north (N) or south (S), and a similar bit field with north and south replaced by east and west for longitude. The format of the velocity field will be a speed field in kilometers per hour and a direction field measured in degrees relative to true north [19].

The GPS system can become less accurate when it is not in clear view of the sky. In order to achieve the most accurate position and velocity data possible, several systems for improving GPS accuracy through augmentation have been developed. The main system applicable to this project is the Wide Area Augmentation System, developed by the FAA and made available to North America. WAAS uses ground based reference stations to make corrections which can be used by WAAS enabled receivers to obtain more accurate position data. The WAAS specification declares that the 95% horizontal and vertical error

will not exceed 7.6 meters at any location [20]. Testing of this system shows that this specification is well exceeded in most locations, specifically, that the maximum 95% horizontal error was .922 meters with LPV being available a minimum of 96.23% of the time [21]. This project will benefit greatly from the use of a GPS module capable of using the WAAS system when in North America, and could be modified to use other Augmentation systems in other parts of the world. Differential GPS (DGPS) could also provide an improvement in accuracy, and can be mimicked by measuring the difference between a current signal and a stored signal, but true DGPS would require additional equipment and could quickly become too costly. It can be expected that if the stored signal is updated on a daily basis, which it will be, this system may see some improvement due to the cancellation of spatially correlated position errors. Assisted GPS (AGPS) can also be used as an augmentation system if it is found that the Time to First Fix (TTFF) is too long, but will require additional hardware and internet or cellular access to provide any improvement. An Inertial Measurement Unit (IMU), a device capable of measuring accelerations and orientations to determine precise movements, could be used in addition with the GPS system to provide more accurate position data using a Kalman Filter, allowing for more precise positions at the cost of an IMU. The reason that an IMU is not considered a practical option for a standalone system is due to the tendency to drift over time. A use of one or more of these augmentation systems could improve the accuracy over GPS drastically, and modules capable of integrating multiple augmentation methods will be evaluated based on overall accuracy and cost.

In the interest of a system that works with an acceptable degree of accuracy everywhere in the United States of America, GPS will be used as the primary location detection system. The location detection subsystem for Puppy Pal will be implemented using GPS augmented with WAAS to improve accuracy, meaning that the selected GPS system must be WAAS capable. The possibility of using Wi-Fi based augmentation will also be considered as a way to improve accuracy and TTFF indoors and in urban environments if GPS is found to be insufficient, meaning that the selected GPS system should also be A-GPS capable. A final method of augmentation that the module should be equipped for is the use of an Inertial Measurement Unit (IMU). In the interest of simplicity, a fully functional GPS module will be used, which will communicate serially with the main microcontroller on the ball. The NMEA specification dictates EIA-422 (RS-422) at a rate of 4800 bits per second, with 8 bits of data, no parity bits and one stop bit as the standard for serial communication. This type of communication is compatible with the UART of the main processor but may require the use of a level shifter to match the digital input and output voltages of the separate devices. The location detection subsystem must be able to determine the location of two objects, the stationary base charging station, and the moving ball. This could be accomplished using two GPS units, which has the advantage of determining when the base charging station is moved during play and may cancel correlated errors similar to DGPS systems, but would double the cost of a GPS system and place a much larger requirement on the communication link.

Another option for determining the location of both systems is to require that the ball be placed on the charging station when the base charging station is moved, allowing a single GPS receiver on the ball to determine and store the location of the base charging station for use during the upcoming use. The advantages of a single GPS receiver are that quicker calculations may be made because the position of the base charging station does not need to be transmitted, it can simply be read from memory for comparisons, but also this greatly reduces the complexity. Since the base charging station is not expected to move on a regular basis, a single GPS design will be used, allowing a simpler design at the cost of requiring a short location storage period when desired play area is moved. When designing the PCB layout, care must be taken in the positioning of the GPS and any IMU or accelerometer, and all instructions and suggestions in the devices datasheet will be followed. Nearly all GPS modules are required to be facing upwards and may have other requirements that should be considered early in the PCB layout design stage. IMUs and accelerometers have special requirements of placement with respect to hardware mounting locations to minimize unnecessary vibration, and all specifications and suggestions in the device's datasheet will be followed. The GPS chosen for this design is the Maestro A2100-B, for its WAAS support, A-GPS support, and accelerometer support primarily, but the device was also found to have typical power requirements, typical standalone GPS specifications, and a reasonable cost. In addition, if the accelerometer based augmentation is chosen, firmware support for the KXSD9 accelerometer exists and will be used. This device will require an external antenna, which has been chosen to be an active antenna, requiring a maximum 5V supply voltage, maximum 50mA supply current, maximum 1.5dB noise figure, and a gain between 15dB and 20dB including cable losses. The SL1206 antenna from Sarantel is expected to meet these requirements including cable losses.

In Table 3.15, multiple GPS modules are compared. Although the VPN1513 has many impressive features, it is too expensive and lies outside of the scope of the project.

GPS Module	WAAS?	A-GPS?	Power Demands (volts)	Price	Special Features?
Maestro A2100-B	Yes	Yes	1.7 – 1.9	$17.57	Accelerometer support
Jupiter SE880	Yes	Yes, for a trial period	1.8	$13.76	No
VPN1513 GPS Receiver	Yes	No	3.3	$44.99	Can track up to 20 satellites at a time; carries rechargeable battery; on-board 3.3V regulator

Table 3.15 Comparison of various GPS modules.

Unfortunately, no GPS modules were available within our budgetary requirements which could provide accurate enough position and heading data. Additionally, GPS cannot determine heading direction of a stationary object, which is necessary for accurate movement.

3.3.7.2 Wi-Fi Positioning Systems

Wi-Fi Positioning Systems (WPS) have the advantage of working very well in urban environments with a high density of publicly broadcasted Wi-Fi access points. WPS works by using the Received Signal Strength Indicator (RSSI) as specified in IEEE 802.11 standard. WPS has the drawback of requiring access to a publicly broadcasting Wi-Fi access point which has had its approximate position previously mapped, many of which are mapped and can be accessed via Google location based services. A WPS module would require additional hardware including a minimum of a Wi-Fi receiver and Antenna, but would benefit by adding a Wi-Fi transceiver in order to allow AGPS augmentation of the GPS module.

3.3.7.3 Multilateration

Multilateration uses the differences in Time Distance of Arrival (TDOA) to determine of multiple signals from separate but synchronized sources, called base stations, of known location to calculate the location of the receiving device. This is essentially how GPS works, however, errors caused by ionosphere delay and other atmospheric effects are eliminated by using base stations on earth. Four base stations are required to obtain three TDOA values which can be used to calculate the receiver's three dimensional location, however using base stations transmitting a signal from a known height and a receiver which is always on the ground, the two dimensional position on the ground could be calculated using three base stations. Many different types of signals can be used, however, radio frequency (RF), infrared (IR), ultrasonic are the most common. Issues with using RF and IR signals are that when using base stations in proximity, errors in synchronization between stations and errors in the receiver's timing system could be large for the low cost components this design requires. The ultrasonic signals provide a larger TDOA for the same proximity of base stations due to the speed of sound being much lower than the speed of light, making the errors in timing and synchronization much less significant, and could provide more accurate data. Possible issues that may be encountered with an ultrasonic are the limited range would cause failure of the system when the ball is taken out of the sensor's range and the possibility that although humans won't hear the ultrasonic sensor, a dog may. Dogs are capable of hearing much higher frequencies, and while this does not eliminate this option, it will impose further requirements which may not be met by existing modules. While the multilateration methods discussed, excluding GPS, may be inadequate for the main location detection system's

requirements, the improved close range accuracy of ultrasonic sensors could be very beneficial in close range. This could be used in conjunction with other location systems, such as GPS, to allow precise location detection when in close proximity to the base station, allowing the system to become accurate enough for the device to guide itself back onto the charger.

3.4 Possible Architectures and Diagrams

3.4.1 Hardware Block Diagrams

3.4.1.1 Ball Block Diagram

As discussed in previous sections there are three core systems in the overall project: the ball, the charging station, and the collar the dog will be wearing. Figure 3.13 displays the hardware block diagram inside of the ball and the connections to different hardware. The main power supply in the ball is a 12 volt battery, the MCU in the ball is powered by a regulated 5 volts, the Bluetooth module is powered by a 3.3 regulated voltage, and the motor control can push a max of 12 volts with the 5 volts output triggering the voltage amplification. For the wireless charging application to operate, a wireless power receiver and battery charger will need to be implemented. The wireless power receiver will input the power from the charging station, then the power obtained will be used to charge the 12 volt battery. One note in addition to the diagram displayed below is to acknowledge that the charging station and dog collar will not be a part of the circuitry inside the ball. As those are completely different and separate systems from the ball.

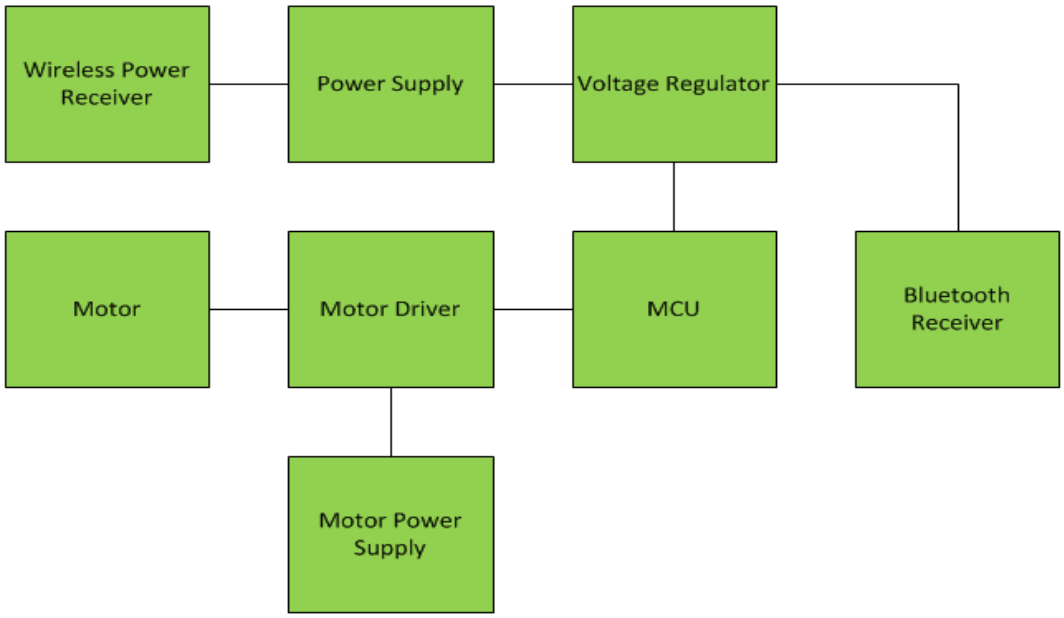

Figure 3.13 Hardware Block Diagram of hardware inside the ball.

3.4.1.2 Base Charging Station

The charging station provides several features necessary for the function of Puppy Pal. The primary function is to provide the transmitter for wireless charging, however, it will also provide a reference point for defining the play area and contain a motion sensor. The base charging station will take power from a household outlet and convert this to DC power used by the wireless power system to charge Puppy Pal. The basic functionality of this device and flow of signals is described in Figure 3.14.

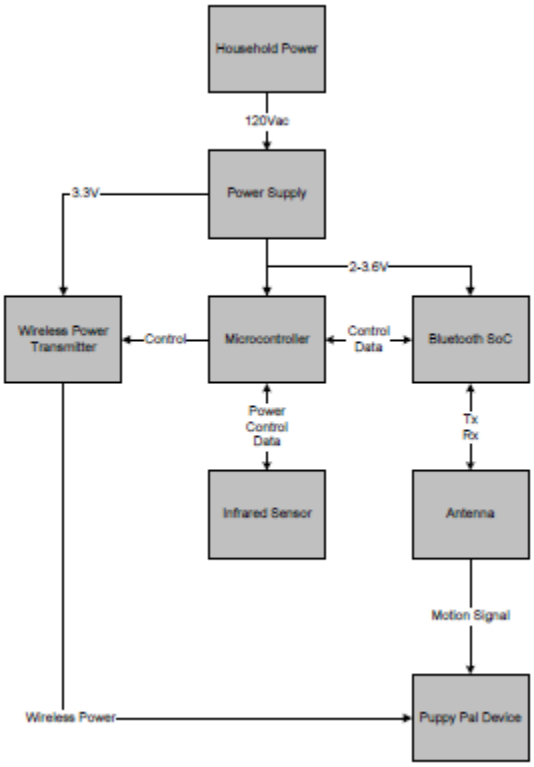

Figure 3.14 Block diagram showing the flow of control, data, and power in the Base Charging Station.

3.4.1.3 Collar

The need for a collar arises from the requirement that this device stop the dog's destructive behaviors. The collar will sense when the dog is awake and moving, and communicate the need for a distraction to Puppy Pal. This collar must be low power, to promote a long battery life, using only two AAA batteries. The approach to obtaining the lowest power will be to leave an accelerometer on and provide an interrupt to the communication and processing system when the threshold for movement has been met. This movement data will then be processed, and if it is determined that the dog is awake, a single message is transmitted to wake Puppy Pal, if not, the device will return to sleep mode. The basic functionality of this device and flow of signals is described in Figure 3.15.

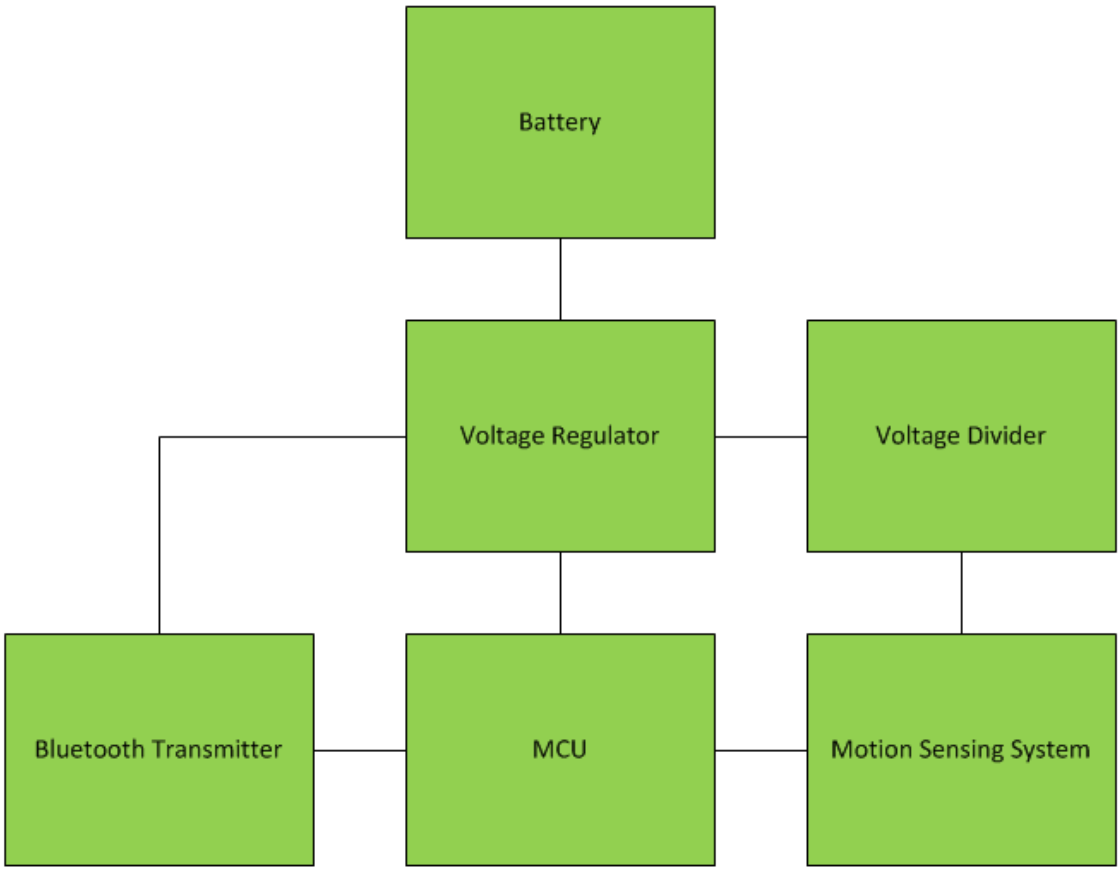

Figure 3.15 Block diagram showing the flow of control, data, and power in the Collar.

3.4.2 Remote Control Diagram

Figure 3.16 displays a diagram visualizing the process of determining the direction of movement of the main system. From observing the diagram, when the device is set to remote control mode, it is seen that the signal sent out of the Android device works directly with the motor control(s). How the motor control operates is dependent on what character the MCU reads in from the UART. The character will be sent from the Android device and received from the Bluetooth module interfaced to the MCU, and the characters read in will determine the direction of movement. It is important to set each command to a different character. If there are two characters set to two separate actions, it may cause problems when the control unit is reading in information. For example, if turning right and changing modes are set to the same character, when the user sends the command to turn right there is a high chance the system will not obey and change the mode of the system. This algorithm is implemented for other user control methods as well. If an analog control wants to be used, specific signals will represent specific actions.

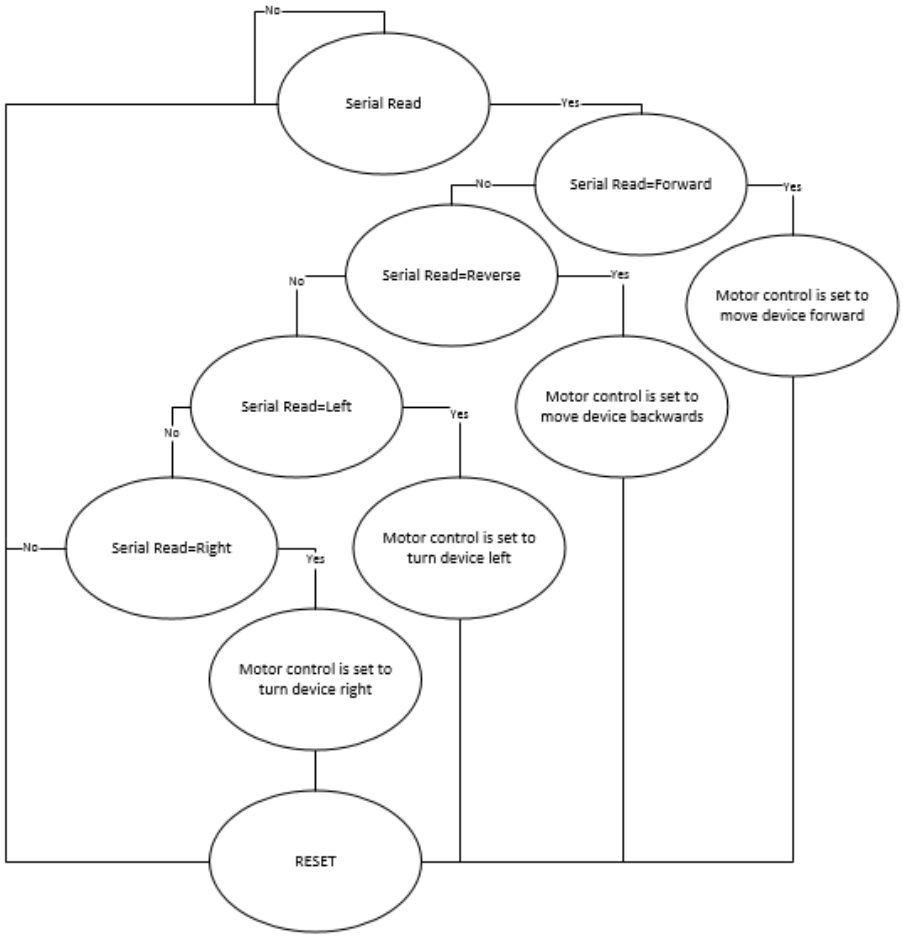

Figure 3.16 Diagram displaying how the remote control mode will be implemented.

3.4.3 Software Block Diagram

Figure 3.17 shows a block diagram of the Puppy Pal software. The diagram shows a simplified overview of major data flow between the different subsystems of the software. As show, information eventually gets to the hardware abstraction layer, the HardwareInterface.

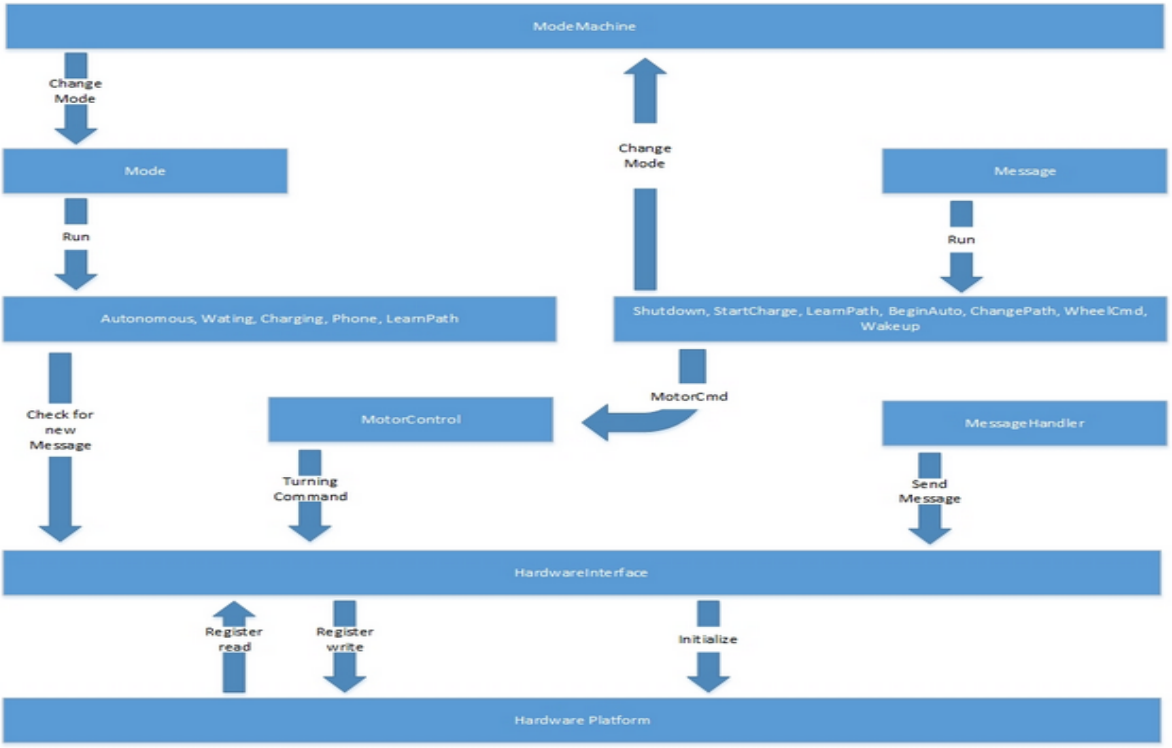

Figure 3.17 Block diagram of Puppy Pal software

4 Project Hardware and Software Design

4.1 Initial Design Architecture and Diagrams

The traditional design of a mobile device is the chassis and wheels design. For this device, the traditional design has too many external components that could be easily chewed off by a curious dog. In order to maximize the durability of this device, all components had to be encapsulated in a rugged shell, allowing no point for a dog's teeth to grip. This greatly increases durability, but posed more obstacles in terms of mechanical design. The mechanical system attempts to maximize acceleration, deceleration and steering ability and top speed, while minimizing the potential for loss of control.

4.1.1 Rotational Motion

The basic premise of this design is Newton's third law of motion: every action has an equal and opposite reaction. In this system, a pair of motors causes the exterior shell to rotate with respect to the interior components, producing a motion. The reason for two motors, is steering. One motor will provide the forward motion, the more powerful motor, and one will provide angular steering by spinning the device about its vertical axis. This design can be seen in the set of two dimensional renderings in Figure 4.1, Figure 4.2, and Figure 4.3. The connections mechanically supporting the internal devices come in two forms, bumpers and joints. The joints, which are only used to support the axle, will be firmly attached and should not slide, twist or move in any way from their initial position during operation. The bumpers will be low friction joints which are only used to support the weight of the device and aid the main axle support. The first motor, which needs to be more powerful, will be the main motor which will provide motion in either forwards or backwards in a path directed orthogonal to its axis, which is the axis the axle lies in, and the vertical axis, the axis in which the shaft of the steering motor lies. The direction cannot be changed by the main motor, but as the second motor, the steering motor, rotates quickly, the outer shell, which is firmly jointed to the axis, will rotate with respect to the internal components. The inertia of the internal components will cause the device to also rotate with respect to the ground, although to a lesser degree. This design's acceleration and deceleration is limited by the torque which can be produced without causing the counterweight, the weight of the internal devices, to rotate more than a quarter turn in either direction.

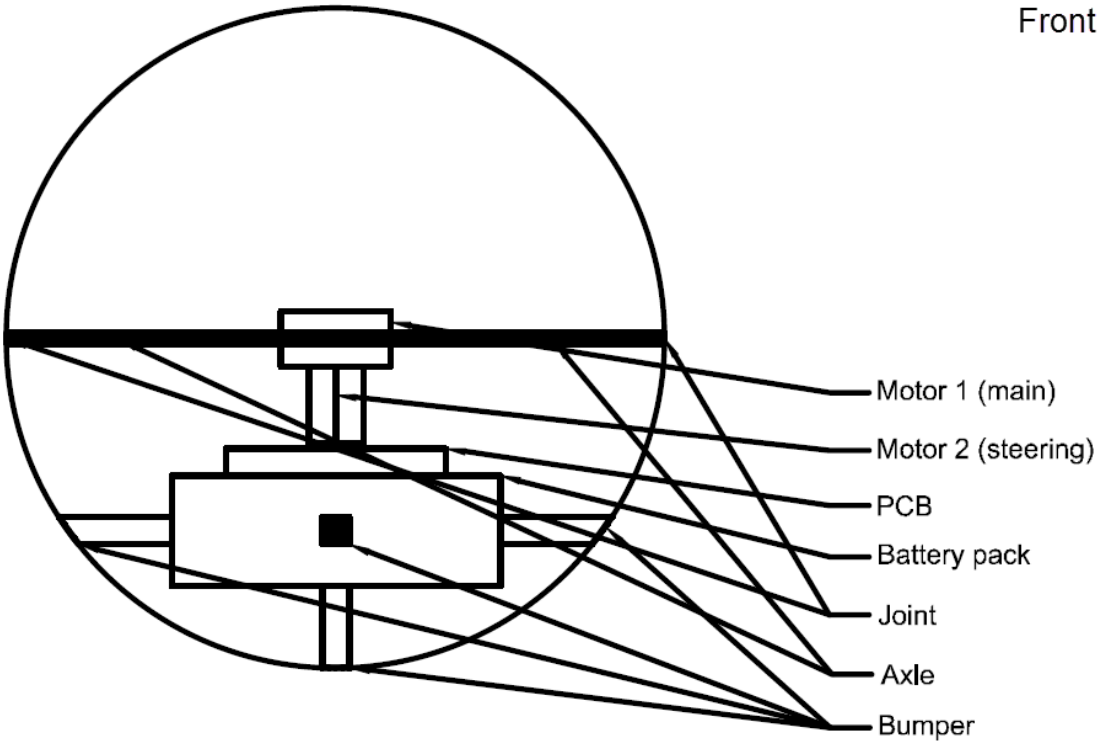

Figure 4.1 Front view of the mechanical design powered by rotational motion showing how components interact.

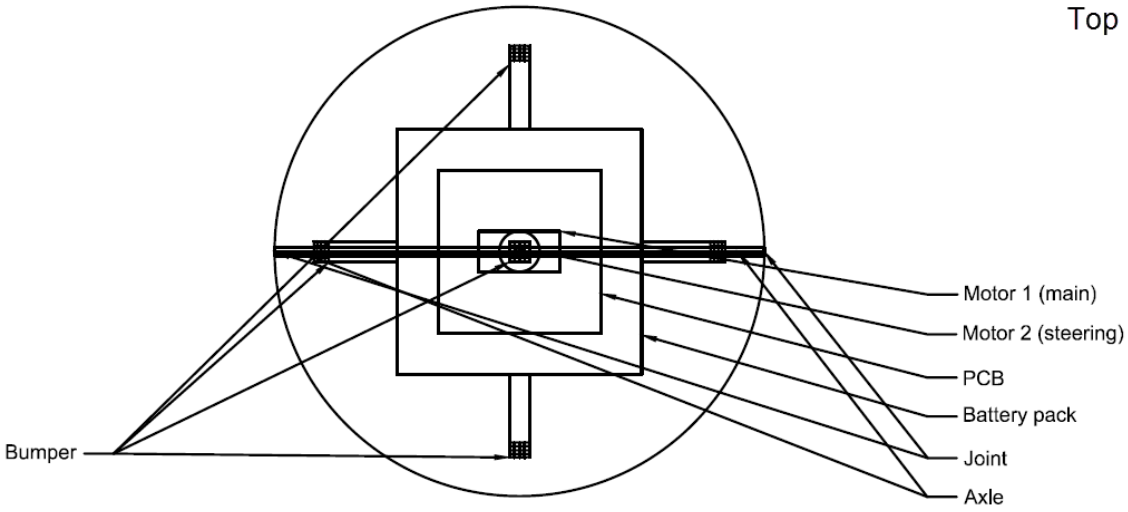

Figure 4.2 Top view of the mechanical design powered by rotational motion showing how components interact.

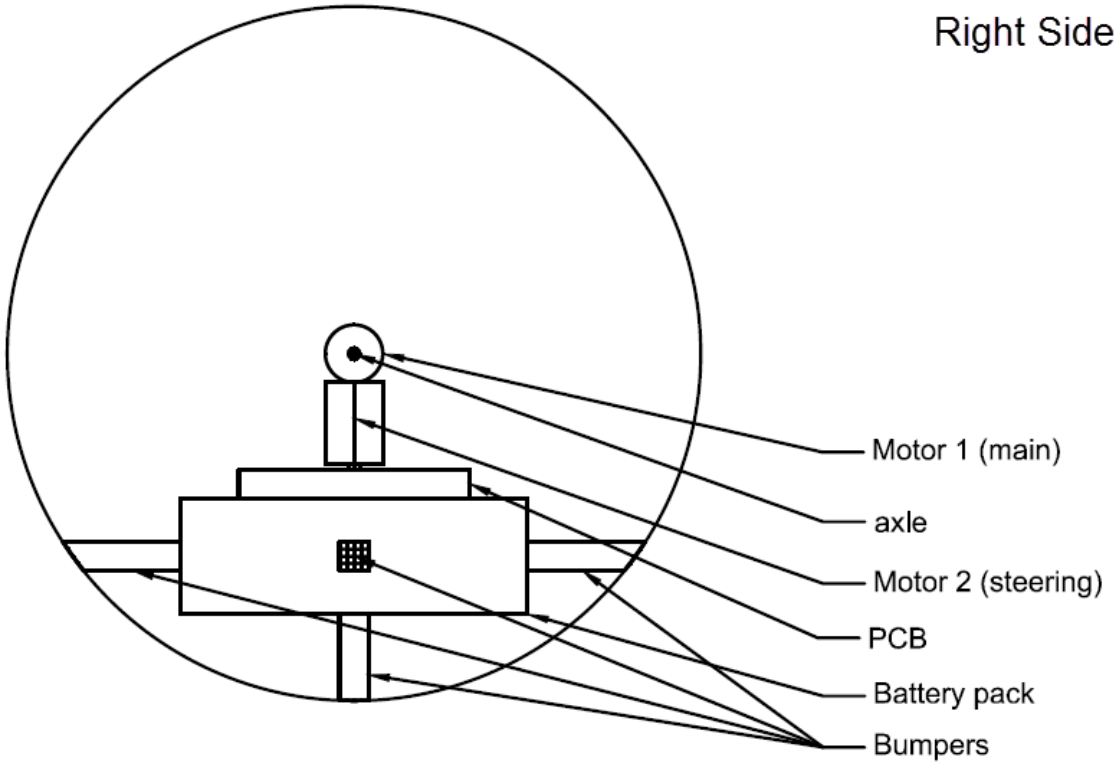

Figure 4.3 Right side view of the mechanical design powered by rotational motion showing how components interact.

4.1.2 Mobile Center of Mass

The basic premise for this design is that gravity creates a force on an object, and a force applied at a distance away from the center of mass will create a torque. This torque will create motion in the direction of the two dimensional projection of the center of mass, allowing the device to move in two dimensions. An easy way to visualize this design is the familiar image of a hamster running inside a hamster wheel producing rotation in one direction. This idea can be extended to a hamster running in a ball, by running in varying directions, rotations in varying directions can now produce motion in two dimensions. In this design, the hamster is mimicked by a pair of motors. In order to move the center of mass in two dimensions, this design will require two motors and a control system. One motor will act to change the angle of the center of mass with respect to the vertical axis and one will work to change the azimuthal angle of the center of mass. The torque created by this design will be proportional to the two dimensional projection of the distance from the center of mass to the center of rotation, the mass, and the acceleration of the object caused by gravity. The acceleration (a) will be proportional to the quotient of the torque produced (T) and the radius of the shell (r_{shell}) and will be in the direction of the two dimensional projection of the center of mass.

$$T = \sqrt{{r_x}^2 + {r_y}^2} \times (m * 9.81) \quad and \quad a_{forward} = \frac{T}{r_{shell} \times m}$$

This design minimizes instability issues, however, the acceleration is limited by the force of gravity and the distance the center of mass can be located from the center of rotation, where other designs are capable accelerating and decelerating at rates only limited by the components used. Two dimensional drawings can be seen in Figures 4.4, the front, Figure 4.5, the top, and Figure 4.6, the right side, to give a sense of how the pair of motors will work together to move the center of mass and how components will fit together.

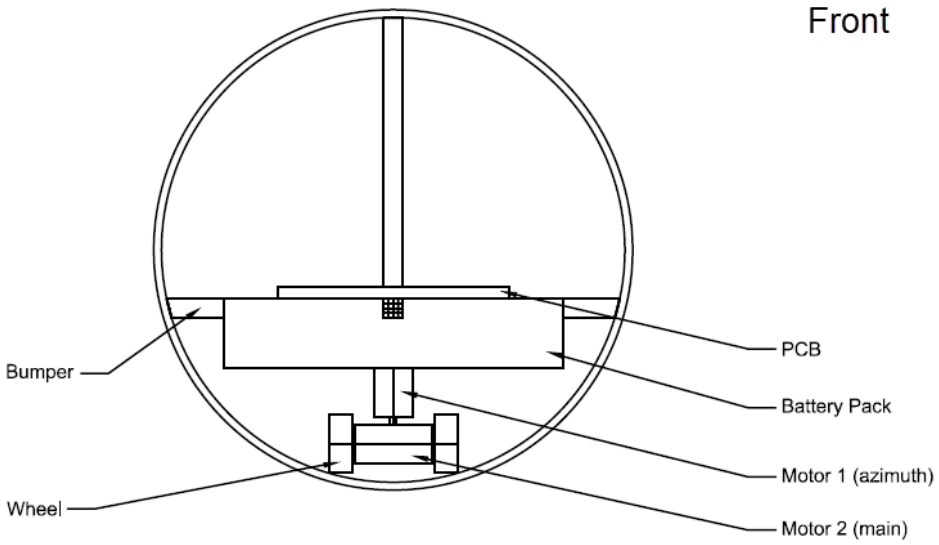

Figure 4.4 Front view of the mechanical design powered by shifting the position of the center of mass, showing how components interact.

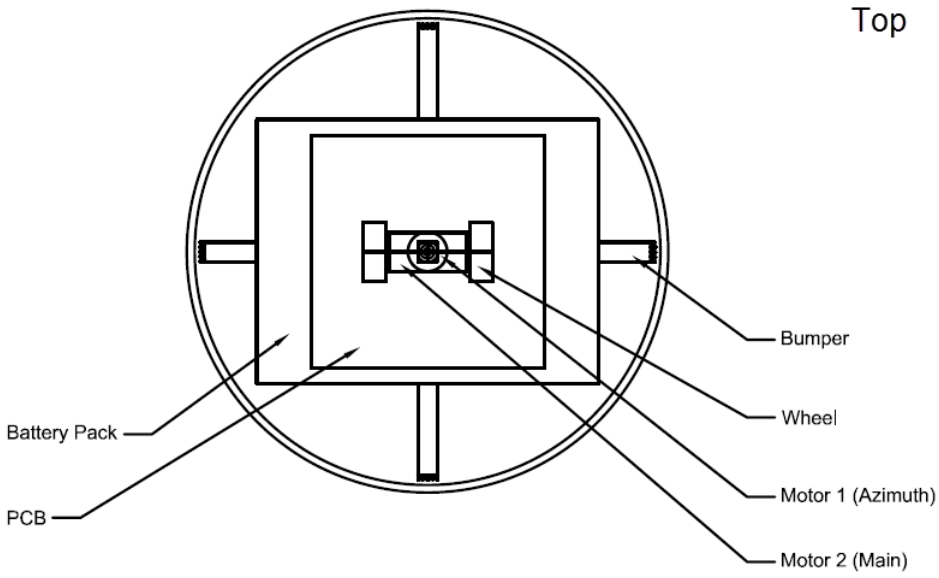

Figure 4.5 Top view of the mechanical design powered by shifting the position of the center of mass, showing how components interact.

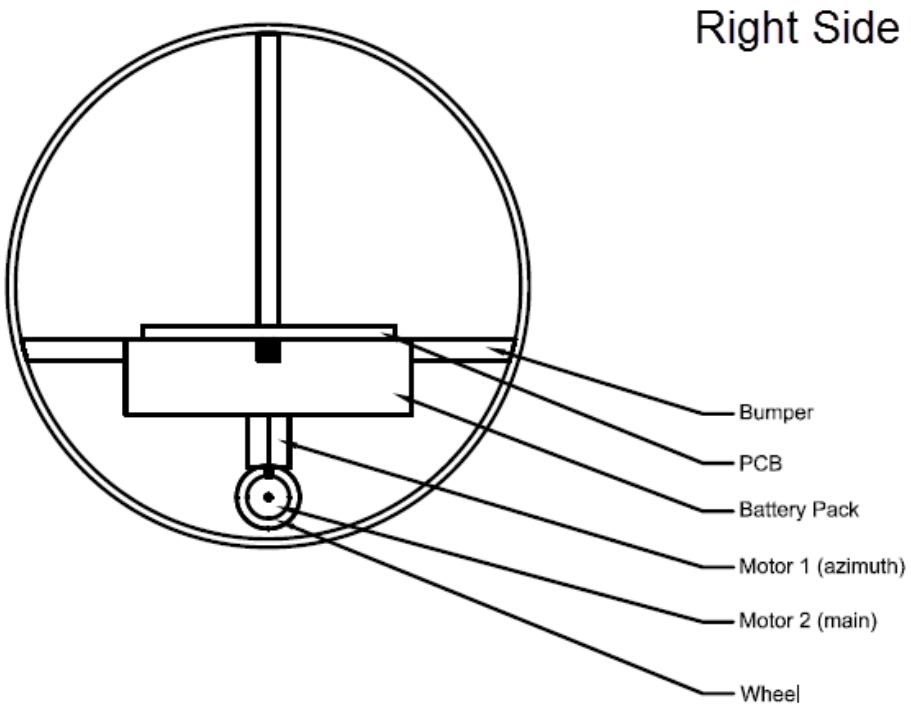

Figure 4.6 Right side view of the mechanical design powered by shifting the position of the center of mass, showing how components interact.

Another way to implement this design is to place the two motors in a parallel direction, on opposite hemispheres positioned symmetrically with respect to the direction of motion, with the average angular acceleration (α) of the two motors being proportional to the forward linear acceleration, and the difference between the double integral of the angular accelerations with respect to the time the acceleration difference occurred being proportional to the steering angle assuming a starting angle of zero. The rate at which the device turns will also be inversely proportional to the distance perpendicular to the direction of motion between the two motors (d_x).

$$\alpha_{forward} \propto \frac{\alpha_{motor1} + \alpha_{motor2}}{2} \quad and \quad \theta_{steering} \propto \iint_0^t \frac{[\alpha_{motor1} - \alpha_{motor2}]}{d_x} dt$$

Possible issues with this design could be encountered when steering too quickly. In particular, a temporary loss of control could occur if the device rotates far enough that the rotation from momentum is great enough to cause the device to rotate on an axis skew to the axis of the motor rotation.

Another possible implementation could be to place the two motors perpendicular to one another, both placed at the center of the device as seen from their perspective. The acceleration produced by the two motors would be found through vector addition, with the individual accelerations produced by the

separate motors acting as perpendicular vectors to create the overall velocity vector. The magnitude would be found by taking the Euclidian norm of the two angular acceleration of the motors (α) and the angle of steering would be found by taking the inverse tangent of the quotient of the double integral of two angular accelerations with respect to time and substituting the time which the acceleration occurred for.

$$a_{forward} \propto \sqrt{{\alpha_{motor1}}^2 + {\alpha_{motor2}}^2} \quad and \quad \theta_{steering} \propto \tan^{-1} \iint_0^t \frac{\alpha_{motor1}}{\alpha_{motor2}} dt$$

All of the designs mentioned in this section may have a stationary center, meaning that the center makes no more than a quarter of a rotation from its equilibrium position, or a free rotating center. The advantage to the free rotating center is that it allows for faster acceleration. Downfalls include an added requirement of a specialized antenna for the GPS, since GPS requires the clearest possible view of the sky, and a rotating center will not always face the sky, also the center of mass must be located very near to the center of rotation in order to minimize vibration. The stationary center, however, would actually benefit from a center of mass located far from the center, to allow for a greater torque to be applied without rotation. The stationary center also offers a greater final velocity of approximately double because the rotation is with reference to zero rotation, as opposed to the rotating center, which is with reference to a rotation in the opposite direction. Benefits from the stationary center also include greatly improved simplicity and functionality of the GPS location system which benefits from an antenna which has performance related to how clear view of the sky its view of the sky is. With the stationary center, the GPS antenna can be mounted on the highest sky facing part of the device, allowing the antenna to always have the best possible view of the sky for maximum accuracy.

4.1.3 Hybrid

Another possible mechanical design could be to create a system that takes advantage of the benefits of both systems. Since the rotational system allows for the greatest acceleration, a powerful motor could provide a linear driving force, while a smaller motor could move the center of mass in a direction perpendicular to the direction of motion to allow for steering. This would require that the center be stationary to allow the center of mass movement system to work and would only allow for powerful motion in one direction that could not be adjusted when the device is stationary. The stationary center also means that this design will benefit from the simplified design and improved performance of the GPS location detection subsystem. To mitigate this issue the device could benefit from using three motors, the additional motor being an azimuthal steering motor, allowing the device to make more abrupt turns at slow or zero speed and make turns at higher speed while still remaining stable.

4.2 Mechanical Subsystem

Puppy Pal is a mobile robot. Its spherical shape presented a less traditional challenge for design. A chassis with wheels and motors did not suffice. For this project, the mechanical system's design considered the use of wheels to spin the surface of the ball and the different ways shifting the center of mass can drive the ball's movement. The device needed to be able to accelerate and decelerate quickly, maintain a constant speed, and stay balanced while stationary and along a straight path.

4.2.1 Design

In this section, the mechanical designs considered for the project are discussed. Their merits and faults will be explored, along with their possible interactions with other subsystems. The design most appropriate was be chosen based on the cost, feasibility, and difficulty involved in building and controlling it during the prototype phase of the project.

Counterweight Design: The counterweight design uses changes in the center of gravity to drive the device's motion. A pair of motors is used to move the weight in the desired direction. The servo motor steers the ball and the drive motor pushes the ball in that direction. While the weight tries to move forward, the framework attached to it and the inside of Puppy Pal are pulled along. The entire system tries to balance where the weight lies. The entire system may rock in place until the counterweight has stopped completely. This rocking may confuse the control system into believe the system is still in motion. To counteract this, sensors detect this rotational motion and inform the controller to react accordingly.

Rotating Wheel Design: The rotating wheel design relies on the interaction between the spherical enclosure and a wheel inside of it. A motor moves the wheel forward or backward. This drives Puppy Pal forward. A servo motor rotates the wheel for steering. To create more torque, weights are attached to the wheel. If the wheel climbs along the inside surface of the ball, the center of gravity forces the entire ball to go forward. Such a system is simple and allows for clear instructions that do not require a good deal of clock time for decisions to be made; Puppy Pal reacts to its control commands quickly. The control system for this subsystem has to take into account the orientation of the wheel and how quickly the ball moves. The difficulty in this design is the wheel moving along the inner surface of Puppy Pal. The armature supporting the wheel, weights, and motors needs the range of motion to face any direction and move forward. This might bring the platform that houses the PCB with it. For this issue, the platform needs to be able to rotate slightly with the rotation of the steering arm.

Dual Wheel Design: The use of two wheels is the conservative choice. Already proven effective in the Sphero project discussed in section 3.1.1, this design uses two wheels to drive Puppy Pal and choose the direction of motion. Depending on the proposed direction, the wheels rotate in opposing directions to force the ball to turn the required amount and continue its heading. Another solution to this obstacle is the wheels rotating in the same direction but at different frequencies. A feedback control system with gyroscopes and accelerometers would need to be incorporated into the design to steer effectively. The dual wheel design has the risk of slipping. To keep the wheels in place at the bottom of the device, a bearing, much like the one used in the Sphero project, could be included to brace the entire system. In addition, bumpers along the bottom of the inner surface can help keep the wheel in place by pushing it back to the center when it strays.

Linearly Shifted Weight Design: The mechanical system in this design also uses the change in the center of gravity to drive motion. Within the spherical enclosure, three linear actuators are arranged orthogonally. They are braced and attached to the enclosure. Along the movable ends of the actuators, weights are arranged. These weights are forced outward to create torque. The actuator parallel to the ground and facing the correct direction pushes the weight forward. As the ball rolls, the actuator pulls the weight back. When another actuator is parallel to the ground and facing the correct direction, its weight will be pushed. This repeats to drive simple forward motion. One of the problems with this design is control. The decision of which actuator should extend and which should retract its weight requires the use of accelerometers to find their respective orientations. Steering is another obstacle. In order to move in the desired direction, two actuators have to be activated. They do not extend completely, only the amount needed to head in the right direction. An algorithm that considers the current speed, heading, and how far each actuator is extended has to then calculate where the actuators have to move their weights to. This is complicated. Instead of nearly instantaneous steering, Puppy Pal would spend much of its time figuring out which actuators to use before actually moving. By the time it takes action, the previous data is no longer relevant and Puppy Pal is going the wrong way. Another issue is the location of the PCB. The actuators do not leave enough room to build a platform. If space for a platform is found, it would then be at risk of being struck by the end of an actuator during extension.

Each design has merits and drawbacks, organized into Table 4.1. The design initially chosen was the rotating wheel. The use of a servo motor makes steering a function exclusively connected to the servo; the other motor just works to drive the wheel forward and backward. The design that was actually used for this project is the dual wheel. It allows for simple commands in the code. This design's method of driving the system is most familiar to the group, and allowed the greatest amount of flexibility as the project was constructed. The motors are controlled separately within the code allowing for steering and spinning in place.

	Pros	Cons
Counterweight	• Simple • Proven effective in other projects • Cheap	• Unreliable braking • Hard to control steering arm
Rotating Wheel	• Precise steering • Moderate torque	• Wheel slipping • Cumbersome steering arm • Waiting for servo might be slow
Dual Wheel	• Precise steering • High torque • Compact • Reliable	• Wheels slipping • Boring
Linearly Shifted Weights	• Unique	• Could destroy the PCB and components on impact • Actuators might collide • Complicated mechanical design

Table 4.1 Comparison of different mechanical systems.

4.2.2 Motors

The rotating wheel design called for the use of a servo motor and a brushless DC motor. This section will discuss the different products that could have met the needs of this design. The servo needs enough torque to turn the steering arm in the correct direction quickly, to allow for enough control to stop turning immediately, and to be small enough to not intrude on the platform holding the PCB or the wheel. The DC motor had to be small enough to fit inside the ball but still be able to drive the toy.

Table 4.2 compares the features of several servo motors. The RF-020TH is the fastest servo, but has the lowest torque. The HS-55 sub-micro servo has more torque, but is not as impressive as the other two servos. The 9g continuous rotation micro servo is lacking in torque and has a reasonable amount of speed.

The HS-422 servo motor is the best choice. The price is reasonable, it has plenty of torque, speed on par with the other two servos, and commonly found operating voltage. The only issue would be the size. If the plastic enclosure used is smaller than planned, then the servo could be too big. If this is the case, the 9g micro servo would be the back-up.

	Operating Voltage (volts)	Operating Current (amperes)	Speed (rpm)	Torque (oz . in)	Price
9g Continuous Rotation Micro Servo	4.8 – 6	Not Given	83.3	18.9	$4.99
HS-422 Servo Motor	4.8 – 6	0.150	62.5	57	$9.99
RF-020TH	2 – 5	0.184	9580	0.222	$1.29
HS-55 Sub-Micro	4.8 – 6	0.150	71.4	16.66	$9.99

Table 4.2 Comparison of different servo motors.

Table 4.3 compares the features of several brushless DC motors. The RC-260RA-2670 motor has the most torque and the highest speed. Its operating voltage range is within that of the HS-422 servo motor, making it possible to use the same voltage regulator for both motors. It is small enough to fit comfortably inside of Puppy Pal and not get in the way of the servo motor. The addition of a gearbox would decrease the speed of the motor, but step up the torque. The main drawback of this motor is its operating current. The current it draws is almost ten times greater than that of its counterparts. Such a difference in power is not worth the greater torque or speed. The RP6858 has an acceptable speed and operating current. Although it is larger than the other motors, it would still fit inside of Puppy Pal. Its supply voltage can be varied during the testing stage. 12V motors were chosen initially, but 6V motors were used in the final prototype.

	Operating Voltage (volts)	Operating Current (amperes)	Speed (rpm)	Torque (oz . in)	Price
RC-260RA-2670	3 – 6	1.43	15290	0.303	$2.75
RF-500TB-18280-R	1 – 3	0.175	2700	0.186	$2.25
ST130-12240-38	1.5 – 3	0.170	3588	0.103	$2.49
RP6858	6 – 24	0.180	2500 (6V) 5430 (12V)	Not Given	$5.95

Table 4.3 Comparison of different DC motors.

4.2.3 Enclosure

Puppy Pal required for a ball that could hold the mechanical system and not hurt a dog's teeth during playtime. The enclosure had to be thick and hard enough to keep the dog from breaking into the ball and destroying the entire toy. The enclosure had a six inch diameter to accommodate the entire mechanical system. The ball was originally salvaged from existing toys, but eventually was custom ordered. The toy used was a hamster ball. It could be taken apart and any pet store has a large selection, both online and on location, for less than $15. A custom order from California Quality Plastics could have cost at least $50. Although this material would be of the highest quality, the project would be more difficult to construct with this product. In addition, the construction process could have been delayed waiting for the enclosure to arrive.

The hamster ball shown in Figure 4.7, the Kritter Krawler, has a seven inch diameter. Part (A) is one of the screws that hold the two hemispheres together. Before the dog interaction tests began, these screws would need to be covered up. The dog could hurt its teeth when trying to gnaw on this part of the ball. Part (B) marks a slit in the ball that acts as an air hole for an animal inside the toy. These slits could have acted as an escape for heat. The motors were at risk of overheating, and the air holes only helped with reducing this possibility. Unfortunately, the slits were another obstacle to dog safety. The slits were large enough for a dog to wedge its teeth inside. With enough strength and leverage, a dog could force open part of the ball, exposing Puppy Pal's innards. It was also possible for a dog to get a tooth stuck, putting the dog at risk of injury. To combat these hazards, the slits would have been covered with Velcro pads. The pads block the openings and make it possible to attach Puppy Pal's fabric skin. The skin covers the screws, the slits, and the plastic. The fabric could have protected the dog from hurting itself and Puppy Pal from being destroyed by an especially curious dog.

Figure 4.7 Hamster ball with parts labeled.

An alternative to the hamster ball and a custom order was a simple plastic globe offered by 1000bulbs.com. This company offers an acrylic ball with a six inch diameter and a 3.25 inch wide opening for $5.95. The wide opening allows for tinkering while the internal structure is being assembled. Unfortunately, the manufacturers do not provide a method for closing the hole once construction is done. The other end of the hub that holds the framework's axle in place may have been attached to a piece of plastic purchased separately to cover up the hole.

The cumbersome customization that came with the plastic globes was outside of the scope of this project. The hamster ball was a simple solution to the enclosure problem. It is tough, sturdy, easy to take apart, and could be purchased in person instead of delivered. In addition, the fabric cover would help protect the dog from hurting itself when playing with the toy.

The ball selected in the end was a simple 6.25 inch plastic globe ordered from Amazon.com. The ball was light, but strong enough for interaction with a dog. Unfortunately, when the mechanical system started running, the wheels got stuck in the slit between the two hemispheres. The wheels stalled in place until there was enough force for the ball to burst open the mechanical system began running outside of the ball. When this problem became apparent, there was not enough time left to find a solution before the deadline.

4.3 Motor Control Subsystem

4.3.1 Design

The mechanical subsystem asked for the design of a motor control system that uses feedback from various sensors and driver control circuits to properly maneuver Puppy Pal. The control system would have consisted of gyroscopes, accelerometers, and encoders. The data collected would be fed to a microcontroller and decide how Puppy Pal should behave in order to follow commands quickly and stay swift and balanced along the way. The flow of information is shown in Figure 4.8 below. In this block diagram, the controller receives data that describes the behavior of the motors and the ball as a whole. The accelerometer measures how quickly Puppy Pal is accelerating in any direction. The gyroscope measures the speed of angular rotation of the PCB the sensor is mounted on to. The encoder finds the angular position and speed of the motor it is associated with.

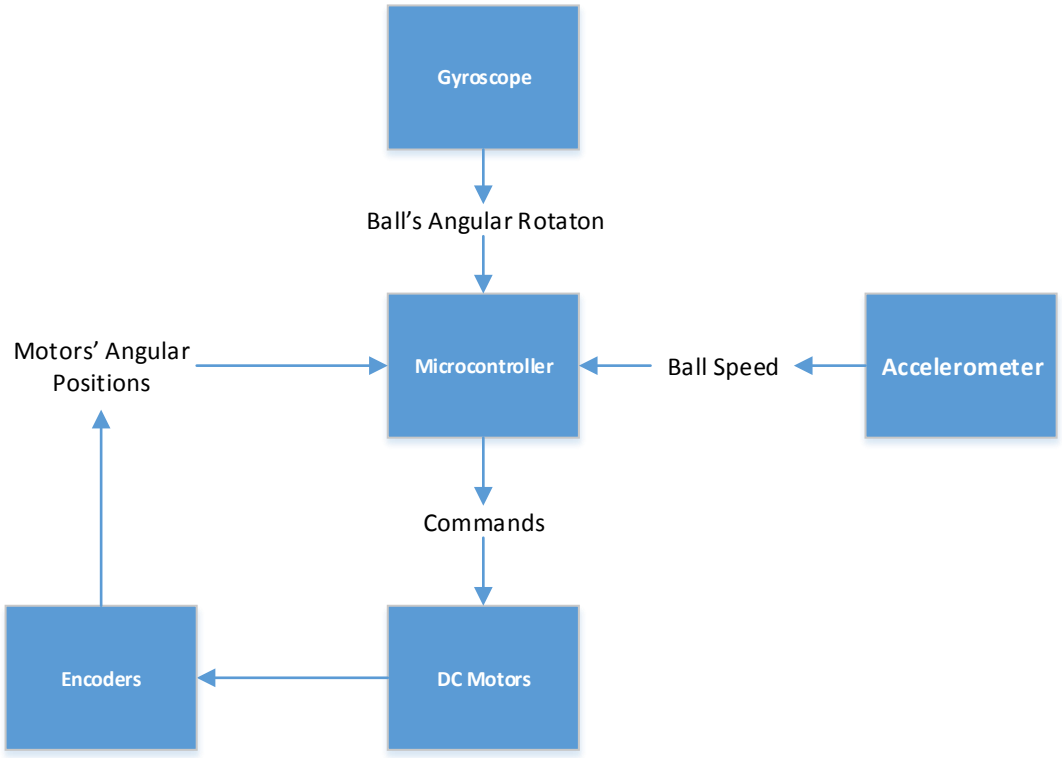

Figure 4.8 Block diagram depicting the flow of data in the motor control system.

4.3.2 Hardware

The parts discussed in this section are considered based on how they could have been incorporated into Puppy Pal's control system. Extra components that would

be needed for proper integration are also discussed, but only in the context of the device they would be associated with.

4.3.2.1 Gyroscopes

The gyroscope considered for this project were small enough to fit on the PCB, sensitive enough to sense the slightest change in stability, and able to communicate with the motor controller seamlessly. This type of sensor tends to constantly measure and update angular acceleration. When converted into a digital signal, much of the output's information is lost. The loss of this data can result in incomplete information being sent to the controller.

LPY550AL: The LPY550AL has been discontinued to make way for newer products. As a result, suppliers have put the device on clearance, reducing the cost of the sensor from $19.95 to $11.95. The price drop made this sensor a sensible candidate for Puppy Pal's feedback control system. This gyroscope measures the angular rate along the x- and y- axes. There are output pins for each axis. It requires a power supply between 2.7 and 3.6V. This range requires the use of a voltage regulator for integration with the rest of the project. The breakout board that comes with this product includes a voltage regulator that works with inputs up to 16V. The output is analog, and there is the option to use an amplified signal. The gyroscope is very sensitive. The amplified output signal can be used to detect movement up to 500°/s. The unamplified output signal can be used to detect movement up to 2000°/s. Both signals have an amplitude of 1V. In order to feed information to the microcontroller, these signals need to be converted to a digital signal. The analog-to-digital converter of the microcontroller could have been used or another one would have been added to the circuit. This sensor is very sensitive and allows for precise detection. However, this level of sensitivity would be too great for Puppy Pal; the gyroscope is meant for balance, not exact location detection. The toy was unlikely to rotate so quickly, making this device too specialized for the project.

L3GD20H: This sensor is what the LPY550AL is being replaced with once it is out of stock. A single chip is available for $19.95, the original price of the LYP550AL. The L3D20H measures the angular rate of change along three axes. The chip would be placed such that the y-axis lies parallel to the part of the platform that is attached to the plastic enclosure. The y-axis output signal would measure angular motion as the ball tilts forward and backward. The x-axis output signal would measure angular motion as the ball wobbles side-to-side. The z-axis would have detected angular motion as Puppy Pal turned in any direction. The gyroscope's sensitivity can be set to measure angular rates up to ±245°/s, ±500°/s, or ±2000°/s. This versatility could have given the project the option to start with less sensitivity and gradually increase the setting as needed. The sensor's data is outputted as a digital signal. This makes the use of an analog-to-digital converter redundant when connecting the gyroscope to the microcontroller. What must be considered instead is the meaning of the signal

and how that could be conveyed. The signal is sent out with the serial communication techniques I^2C and SPI. Another benefit of digital output is noise reduction. The supply voltage is between 2.2 and 3.6V. A voltage regulator would be needed. The breakout board that carries the L3GD20H has a voltage regulator with output 3.3V and input between 2.5 and 5.5V. Instead of being connected to Puppy Pal's power supply, this regulator would have been connected to the regulator that feeds into the microcontroller, which fit within the required range. Another feature of this device is temperature sensing. The output of the sensor is one of the digital signals that can be read via serial communication. The temperature sensor could tell the microcontroller when it is too hot inside of the ball to continue to work efficiently and effectively The L3GD20H was a valuable choice for its variable sensitivity, the ability to detect angular movement on three axes, and the digital output signal it provides. It also makes the addition of a separate temperature sensor redundant.

Hovis Gyro / Accelerometer Sensor: This device has a three axes gyroscope and three axes accelerometer. The price is $30.00, which would be acceptable if this device took the role of an accelerometer as well. The gyroscope has a range of ±2000°/s. The accelerometer has a range of ±16g. The gyroscope is not sensitive enough to measure the small angular rotation that Puppy Pal experienced accurately. The accelerometer's range is enough to detect the shaking of a dog, but not sensitive enough to detect smaller accelerations. The output is a digital signal. The device communicates with the microcontroller via I^2C. The operating voltage is between 2.1V and 3.6V. The Hovis is not sensitive enough to measure the smaller rotations or accelerations.

Table 4.4 compares the features of the gyroscopes. The Hovis was not sensitive enough to measure the smaller rotations of Puppy Pal. The LPY550AL was not sensitive enough either. The gyroscope that would have worked best in this project is L3GD20H.

Gyroscope	Measurement Range (°/s)	Output Signal	Price
LPY550AL	500 / 2000	Analog	$11.95
L3GD20H	245 / 500 / 2000	Analog	$19.95
Hovis Gyro / Accelerometer	2000 16g	Digital	$30.00

Table 4.4 Comparison of different gyroscopes.

4.3.2.2 Accelerometers

If an accelerometer were used, it would measure Puppy Pal's acceleration in any direction. The plane parallel to the ground is the main concern in this subsystem, so a sensor that only measures acceleration along the x- and y-axis would have

been acceptable. The z-axis information would help with telling when Puppy Pal is picked up or dropped. This data would have acted as an alert for the motor control system to halt operations while the toy is airborne.

ADXL335: This triple axis accelerometer and its breakout board are available for $14.95. The sensor can measure acceleration up to 3g, or 29.43 m/s^2. Although this would be enough to measure the normal operation of the ball, it would have been lacking when considering the centripetal force of a shaking dog. According to [22], dogs can experience accelerations up to 20g when shaking themselves dry. It is unlikely for a dog to be able to shake with such vigor while holding Puppy Pal, but the possibility had to still be considered. The sensor can handle a shock of 10,000g and continue to function properly. The great acceleration would be measured as a shock. Another accelerometer that can measure such accelerations could have been added as well. The ADXL335 can be powered with 1.8 to 3.6V. The breakout board does not include a voltage regulator, requiring the addition of a regulator to the project to power the sensor. The output of the sensor is an analog signal for each axis. The bandwidth of each signal can be changed with a capacitor. To change the bandwidth, the 32 kΩ output impedance of the pin has to be taken into account. The option to change the bandwidth makes the ADXL335 compatible with any microcontroller. For monitoring the expected behavior of the ball, this accelerometer was a viable option.

MMA3201KEG: This accelerometer can be sampled from Freescale Semiconductor for free. It can measure acceleration in the x- and y-axis directions within the ±40g range. This range is wide enough to sense when a dog is shaking the Puppy Pal as hard as it can. The output signals are analog and vary based on their respective accelerations. These signals would have needed to be converted into a usable digital signal. Although this device can measure more than other accelerometers considered, the range was too great for analyzing the lower accelerations Puppy Pal goes through when not being handled harshly. This accelerometer was not be used.

LIS331HH: This accelerometer is $27.95 from Sparkfun. The sensor measures acceleration along three perpendicular axes. The measurement range can be set to ±6g, ±12g, or ±24g. It would have been possible to have one LIS331HH for normal motion at 6g and another accelerometer set to 24g to properly measure the acceleration of a shaking dog that is holding onto Puppy Pal. The sensor can be powered with 3V. The output is digital. The LIS331HH can send this 16 bit signal to a control with I^2C or SPI, making it easy to connect to the controller.

The features of the three accelerometers are collected in Table 4.5 below. MMA3201KEG can only measure in two directions and is not sensitive enough for this project. The LIS331HH is versatile, giving three ranges of measurement to choose from. It can send data to a microcontroller more clearly and efficiently than the other accelerometers. However, it is nearly twice the price of the

ADXL335. The ADXL335 would have been the accelerometer used in Puppy Pal's feedback system.

Accelerometer	Measurement Range	Output Signal	Price
ADXL335	±3g	Analog	$14.95
MMA3201KEG	±40g	Analog	$9.18
LIS331HH	±6g, 12g, 24g	Digital	$27.95

Table 4.5 Comparison of different accelerometers.

4.3.2.3 Encoders

One of the most useful features of the TMS320F28069MPN, the Texas Instruments microcontroller initially chosen for this project, is its motor control software. Some of data that an encoder would provide can be collected by the microcontroller automatically. The Piccolo microcontroller utilizes the InstaSPIN-MOTION Speed Control program to simplify motor control. Using its FAST Software Encoder, the Piccolo can estimate a motor's magnetic flux, angular position, shaft speed, and torque automatically once the program has been tuned to that motor [23]. This eliminated the need for an encoder. However, if this solution was found to be too difficult to program during the testing phase; there was not a development board available for practice before interfacing the MCU with the rest of the robot. At this point, the Arduino ATmega2560 was used instead. In case this possibility arose, encoders were considered a possible addition to the design to improve the controller's performance. This section will discuss the different encoders considered. The encoder picked was based on cost, the amount of power it consumes, and if it is compatible with the Piccolo microcontroller initially chosen.

RE08A: This simple encoder has a circuit board with a pull-up resistor already connected to the output pin. It is available for $12.49. This device needs a supply voltage of 5V. The output is either high at 5V when the optical sensor's beam is blocked or low at 0V when the beam is left alone [24]. The encoder can measure rotation up to 1 kHz, which is approximately 60,000 RPM. This greatly exceeds the RP6858 motor's speed of 5430 RPM. A rotor comes with the kit. The rotor is to be attached to the drive motor's shaft and positioned perpendicularly to the RE08A's optical sensor to find the frequency of the motor. This is used by the controller to calculate the motor's position and speed. The motor was expected to be connected to a wheel, making it difficult to find room for the rotor and to use the encoder properly. This issue could not be resolved, so this method was not used in the project. One possibility was to attach the rotor and encoder to the opposite end of the motor.

COM-09117: This encoder is available for $2.95. Its output is a digital signal in gray code. This prevents any gaps in measurements from showing up and feeding false data to the microcontroller. The rotary encoder is used to measure the position and speed of a motor. If a knob is attached and the specific program is written, the encoder can instead dictate how the motor shall behave. This could have been used to test the motor's functionality and as practice for controlling a motor.

Neither encoder would have been particularly helpful in the control system. Although their use could have been part of an interesting side project or test, they were not be part of Puppy Pal.

4.4 Microcontroller

The microcontroller being used is the TMS320F28069MPN of the C2000 series from Texas Instruments. Table 4.6 below shows some of its more important features.

Clock Frequency (MHz)	90
RAM (KB)	96
Flash (KB)	256
PWM Channels	17
UART Channels	2
GPIO Pins	40

Table 4.6 Useful features of the TMS320F28069MPN microcontroller

The processor was as customized as possible and has all the features that the Puppy pal device could use and more. The clock frequency is plenty high and even rivals competitors' like the Sphero and Roomba. There is more than enough flash space to hold anything that will be coded in C++ and will allow the advantage of the languages more useful features like operator overloading, virtual functions, and a small derivative of the Standard Template Library. The STL will come in particularly useful because of all the math and sorting algorithms that it supplies. Pulse Width Modulation will be used exclusively by the motors, and the separate channels allow independent PWM units to act on each individual motor controller. Separate serial communication ports also becomes very useful because there are two wireless communication devices attached to the Puppy Pal. Each triggers a separate interrupt service routine which can be run independently of each other because of the two available channels. There are also a number of GPIO pins that allow any external devices to be connected

to the Puppy Pal that is deemed useful. One of these items will be LEDs to provide basic feedback when debugging and running.

4.4.1 Pin Settings

The only pins being used that are critical to the Puppy Pal device are the UART (SCI) pins for communication with the Bluetooth and GPS receivers. UART on the C2000 series microcontrollers is done with separate pins for transfer and receiving. For receiving, pins 45 and 40, representing SCI-A and SCI-B, will be used for Bluetooth and GPS, respectively. These are tied to control registers SCIRXDA and SCIRXDB in the code. Occasionally a message will need to be sent out to a Bluetooth device. In this case, pin 59 will be used, which is controlled by the SCIRXDB register. A red LED will be attached to pin 66 (GPIO3), which will be used primarily for errors outputs in unit test and debug modes. Similarly, pin 7 (GPIO4) will have a green LED attached to it which will signify a pass or successful operation in unit test and debug modes, respectively. PWM channels EPWM4A and EPWM5A will be used for motor separate motor control and are tied to pins 46 and 43, respectively.

4.4.2 Algorithms

There will be many algorithms used over and over again, the most common being the handling of a new message. At arrival time of a new message, the two bytes will be sent into the *MessageFactory* class, where the first four bits are extracted. The MessageFactory will return a new message of the appropriate type. This new message will then have its *unpack()* member function called with the two bytes of message data as the argument. This algorithm is defined to parse the bits of the message data and set the value of the corresponding public member variable of the message. Now that all the data in the message is filled out, the messages *run()* member function can be called, which will perform whatever the messages intent is.

Each mode has a corresponding *run()* member function that provides the main loop of the system. The one caveat is that each *run()* implementation must call it's *check_message()* member function at the beginning of it's loop. This ensures that new messages are handled as soon as possible after their arrival. The *check_message()* routine is simple: it provokes the *HardwareInterface* class to check if a new message is indeed available. If no new message is available the routine ends execution. Otherwise, The *MessageHandler's handle_message()* member function is called, and the message is handled. Depending on the type of message, the current execution is either continued or changed.

Mode changes are a constant operation in the systems lifetime. Because each mode knows how to run itself, when a mode change occurs, the *ModeMachine* simply sets it's *previous_mode_* private member variable to *current_mode_* and

its *current_mode_* private member variable to the mode that the system is to change into. From here, run on the *current_mode_* can simply be called to start that mode. In the event that an error occurs, the current_mode_ is set back to *previous_mode_* so the system can continue to function.

4.5 Remote Control Mode

As mentioned before to connect to an Android device from the Puppy Pal, the best approach would be to use a Bluetooth network. For specific applications in related to the project, Bluetooth provides the most cost effective and simple interfacing procedures to connect. A possibility of using Bluetooth to connect to the charging station and dog collar may be potentially implemented, however as of now the Bluetooth module will be specifically used to connect the Android device to the MCU on the ball, which will use the UART functionality to read input from the user via Android application.

Other than Bluetooth being more cost effective on a hardware level, it provides the simplest way to integrate on the system. Most Android phones have Bluetooth connectivity, so the system will be designed where all the user has to do is download the application to their phone. Ideally all the user will have to do is connect to the Puppy Pal which will be exactly like how the Android device would connect to any other Bluetooth friendly devices.

4.5.1 Bluetooth Module Hardware

The Bluetooth module that was used to interface the Android device with the MCU on the ball will be the HC-05. The module is a small hardware with the size dimensions of 12.7 x 27 mm and in addition a very simple to use connectivity protocol. The module can use Bluetooth V2.0+EDR with an enhanced data rate of 3 Mbps, with a baseband of 2.4 GHz. Some of the hardware features include a UART interface, programmed input/output control, a minimum operating voltage of 1.8 volts with a nominal operating voltage of 3.3 volts, an I/O voltage of 1.8 to 3.6 volts, a programmable baud rate, and a built in antenna [25]. The HC-05 was configured to be either a slave or master device, in terms of interfacing to the Puppy Pal, the module was configured to be a slave device since the Android will be sending out instructions to the ball's MCU and not vice versa. The baud rate that was used is 9600. The HC-05 module has a digital signal processor embedded in the module, with a built in antenna, RAM, and I/O ports. Figure 4.9 displays a block diagram of the HC-05 module.

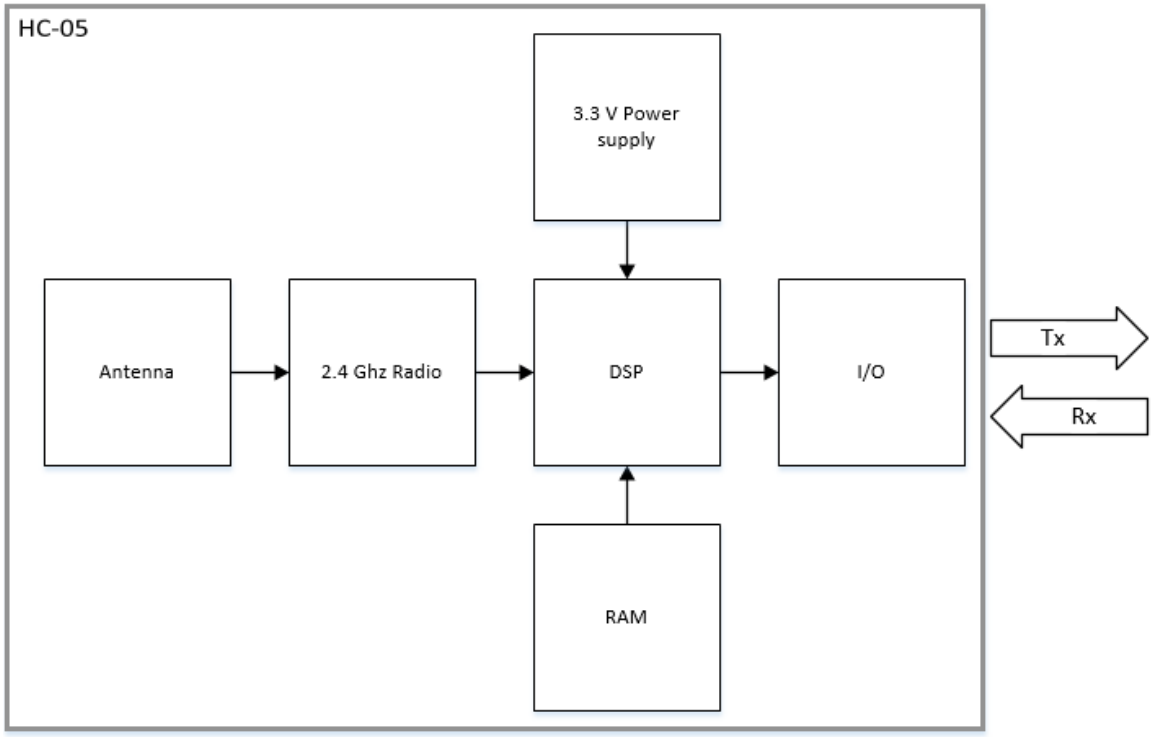

Figure 4.9 Block diagram of HC-05 Bluetooth module

Figure 4.10 displays a simple block diagram of how the HC-05 Bluetooth module connects to the MCU. As observed, it is a simple as setting the GND to GND pins, connecting the power pin of the MCU to the Vcc on the module, however the TXD on the module must be connected to the RX on the MCU and RXD on the module must be connected to the TXD. It must be connected this way because the MCU is receiving what the module is transmitting and the MCU is transmitting what the module will be receiving, however under the applications the project was used for, the RXD pin on the module will not be used. According to most specs observed, the HC-05 module actually worked in a range of a little more than 30 feet. This range is acceptable because the Puppy Pal is designed to be used in a household.

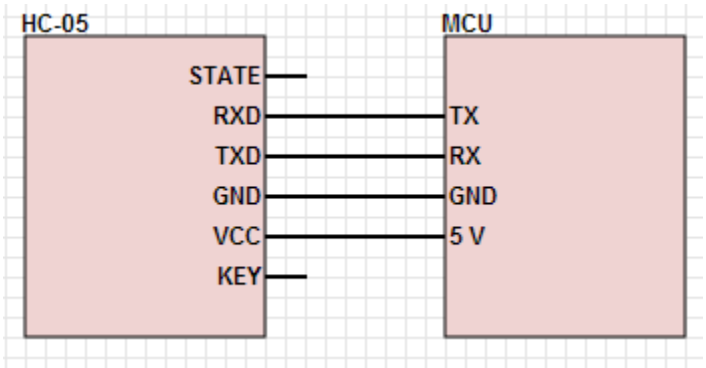

Figure 4.10 Simple block diagram illustrating the connectivity between the MCU and the HC-05 Bluetooth module.

For prototyping and testing, a module that is already soldered was used, as it was a simplified method to connect to the device and observe if the module is receiving the information from the Android device. When the module was integrated onto the PCB, a non-soldered HC-05 was used to solder the connections on to the assigned pins, as it is more effective in looking more presentable and it conserves a little more space. The HC-05 module actually is directly connected to the board instead of having an abundant amount of wiring polluting inside the Puppy Pal's infrastructure.

The HC-05 is configured to be interfaced to the system, in order to configure certain modes, the module uses AT Commands. To configure AT commands, the device was needed to communicate via serial connections with the MCU and a computer using a serial communication software such as HyperTerminal. Since the Arduino UNO was used for prototyping and testing, configuring the module in the Arduino IDE was used. The Arduino IDE comes with an embedded serial UART functionality. The AT commands will be used to primarily to display the specifications of the device and to change the specifications, if it is needed.

Table 4.7 provides simple AT commands that were used to set and/or check certain specs. An AT command that was very significant is finding the MAC address of the module, the MAC address is needed to interface precisely to the Android application. Another AT command that was needed is determining the baud rate or changing the baud rate. This is needed to interface with the microcontroller, and a baud rate of 9600 was used, which is usually a typical baud rate that is used for MCU applications. In addition, to retrieve some sort of connectivity to the Bluetooth module from the Android device, the mobile Android device needed the password and name of the Bluetooth module. As there is an AT command to get the password and name of the module. An AT command is needed to check if the device is configured as a slave or a master device. Also an AT command to change the device to a slave if it is originally configured as a master device may be needed. If the module may somehow get corrupted and will need to reset to its default setting, an AT command restoring to the original setting may be potentially needed. When the module is configured to reset, it sets the pin code back to "1234" and baud rate back to 38400 bps. Under some system debugging circumstances, the firmware version may be needed to view if the Android device will be able to connect to the module. To check the state of the module is a significant aspect of making sure configuring to the Android device is done correctly.

Command (USER)	Response (From HC-05)	Functionality
AT+ADDR	+ADDR:< address of the module> OK	To retrieve the address of the Bluetooth Module
AT+UART=<9600, 1,2>	OK	Set baud rate to 9600
AT+UART?	+UART =<baud rate>,<stop bit>, <parity> OK	Check baud rate, stop bit, and parity
AT+PSWD=<pin set>	OK	Set the pin code for module
AT+PSWD?	+PSWD : <default pin> OK	Check the default pin code of module
AT+NAME=<set name>	OK	Set the name of the module
AT+ROLE=<0 or 1>	OK	Set module to slave or master (0-slave, 1-master)
AT+ROLE?	+ROLE:<0 or 1> OK	Check if the module is slave or master device
AR+ORGL	OK	Sets module back to default state
AT+VERSION	+VERSION :<firmware version> OK	Checks the firmware version of module
AT+STATE?	+ STATE:<state>	Checks the state of device (different states are provided below)

Table 4.7 Table listing relevant AT commands for the HC-05 Bluetooth Module. (Data gathered from electronicaestudio.com)

The state the Bluetooth module are determined by the following potential responses: INITIALIZED, READY, PAIRABLE, PAIRED, INQUIRING, CONNECTING, CONNECTED, DISCONNECTED, and NUKNOW. The state of the device is significant, so it was a good exercise and precaution to use the AT command to check the state of the module before attempting to connect to the MCU or the Android device to reduce the chance of additional debugging.

4.5.2 Android Device

The Android device that was used as a remote controller is the Motorola Atrix HD, which is a smartphone that has Bluetooth connectivity and running the Android OS, also has an embedded accelerometer which may be potentially

used for a tilt control application for the Puppy Pal. Additional specs to look at, the user interface is a multi-touch touchscreen with a Qualcomm Snapdragon, dual core, 1500 MHz processor. The mobile device also has access to BlueTerm a Bluetooth emulator that was used to send data to the Bluetooth module and can be downloaded at the Google Play Store. BlueTerm was used for testing purposes and is used to test if the Android device is transmitting data to the module and also to check if the module is receiving the data. Figure 4.11 illustrates a simple block diagram showing how the Android device is able to have control of the MCU. As observed from the figure below, there are a multiple of processes to go through for the data from the Motorola to reach the MCU. First, an Android application was developed to have access to the Bluetooth functionality of the Atrix. The application provides a way for the user to input control instructions in the form of an ASCII character. The data transmitted will be headed to the HC-05 Bluetooth module, when then it will trigger the MCU to initiate a serial read instruction, where depending on the ASII character received, it will designate a particular action programmed for the Puppy Pal to obey.

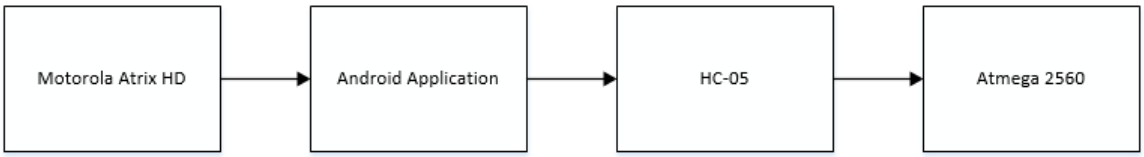

Figure 4.11 Block diagram displaying RC control using Motorola Atrix HD.

4.5.3 Android Application

There are many ways to develop an Android application. One way is to use the Eclipse IDE, this particular workspace is programmed in Java. The Eclipse IDE are created by an open source community so many tutorials and potential reference designs may be used. However, due to the learning curve that comes with learning Java, another technique to develop an Android application may be used. The MIT App Inventor provides a simple way to develop an Android application with little to no background in programming. The way the program works is that it is assembled on a webpage with no coding required. The software uses simple to understand logic blocks that the potential developer will just drag and drop with respect to requested motion.

4.5.4 Algorithm

The algorithm when the Puppy Pal is in remote control mode is basically each motion or action is represented by 4 byte messaging command. The user uses a slider, which will send a specific mode message that will be read by the Bluetooth module. The system will react depending on which message is sent. There will be buttons or slider commands representing the following actions: turning the system on, turning the system off, moving the system left, moving the system

right, and giving the user the ability to configure a play radius. The path selection is dependent on the configurations from the user from the mobile application. In addition, the user can control the speed of the Puppy Pal using the two sliders located on the interface of the Android application. Under the most optimal conditions, the play speed will have a maxim of 255 and a minimum of 0, which are the ranges of the pulse width modulation on the Atmega2560. So when the user moves the slider it will change the motor speed depending on the slider configuration.

4.5.5 Detailed HC-05 Schematic

Figure 4.5.5 illustrates a more detailed schematic of the connections between the MCU and HC-05 Bluetooth module. As observed from the schematic, it is seen that only five pins are needed to operate the module. Those five pins are: GND (pins 13, 14 and 22), 3.3 operating voltage (pin 12), RESET (pin 13), UART-TX (pin 1), and UART-RX (pin 2). There are two methods of connecting the HC-05 to the MCU; one way is using a 5 volt level and the other way is using 3.3 volt level. The 5 volt level connection requires far more components such as a two- level transistor circuit connected to the UART-TX pin, with the first level using positive 5 volts and the second level using negative 5 volts. The 5 volt connection benefits the design because the output voltage from the MCU is 5 V. However using the 3.3 volt level would be the most beneficial as it requires less circuitry and is less complex. To obtain the 3.3 volt operating voltage of the HC-05, a voltage divider was connected between 3.3 V node and 5 V supply voltage from the MCU. Figure 4.12 illustrates a schematic diagram of the connections between the HC-05 and the MCU.

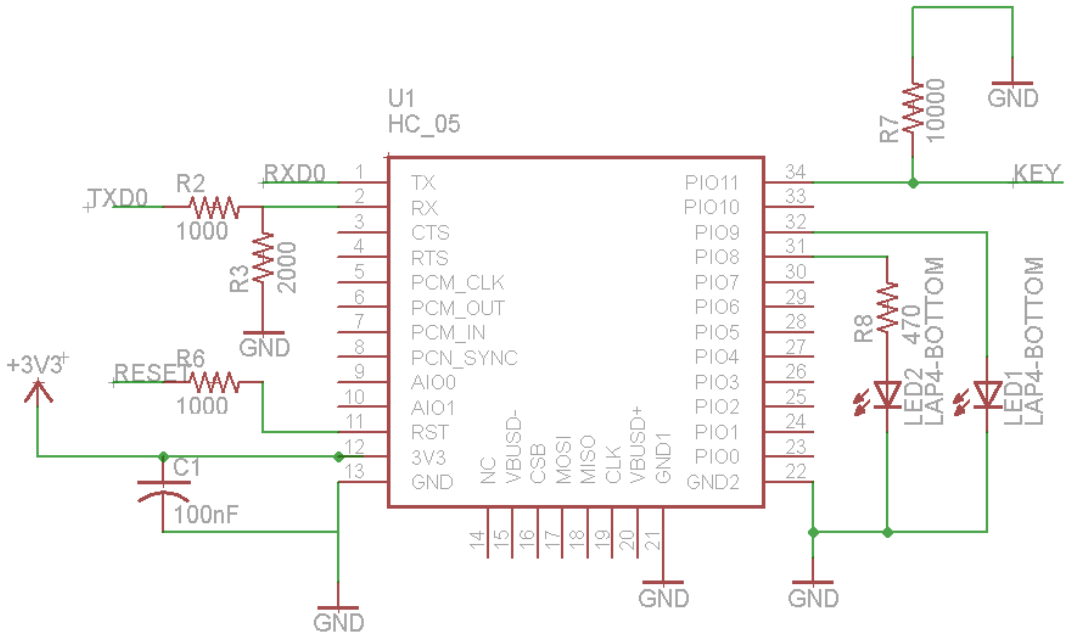

Figure 4.12 Schematic displaying HC-05 and MCU connection

4.6 Motion Detection Subsystem

4.6.1 Collar

The collar will be attached to the dog's collar and will function as the sensor for determining whether the dog is awake or sleeping based on input from an accelerometer. The basic functionality of this system was described in Figure 3, and the implementation of this block diagram is described by the schematic in Figure 13. The two AA batteries in series provide approximately 3V but will vary with the current being drawn and decrease over time. The processing will be done by an Atmega328, communication done by an HC-05 and the accelerometer will be an ADXL 350. Since this supply voltage falls within the range of the accelerometer (ADXL350) and the sum of the two maximum required currents fall well below the maximum current the step down converter can supply, both devices may be powered by the single regulator. In order to obtain the velocity signal from the accelerometer, numerical integration of the acceleration signal can be performed in software. Integration errors will not be an issue since the total time the position will be measured will be relatively short, and integration errors are only an issue with increasingly longer times. In the interest of future improvements to the prototype, the antenna has been wired to a SMA connector allowing multiple antenna types to be tested, and all unused pins on the Bluetooth SoC have been wired to external sockets via a busses (blue lines). When mounting the accelerometer on the PCB, special care must be taken to minimize unnecessary vibration. Any vibration that is not part of the dog's motion is unwanted noise and could produce false interrupts from the accelerometer to the Bluetooth SoC, wasting power and reducing battery life. Minimization of these vibrations can be accomplished by additional screw mounts, as well as intelligent placement of the device with respect to the mounting locations. Suggestions for PCB placement are found in the datasheet of the devices as well as other online sources, and all instructions and suggestions found in the devices datasheet will be considered early in the PCB layout stage and explicitly followed. Figure 3.13 illustrates

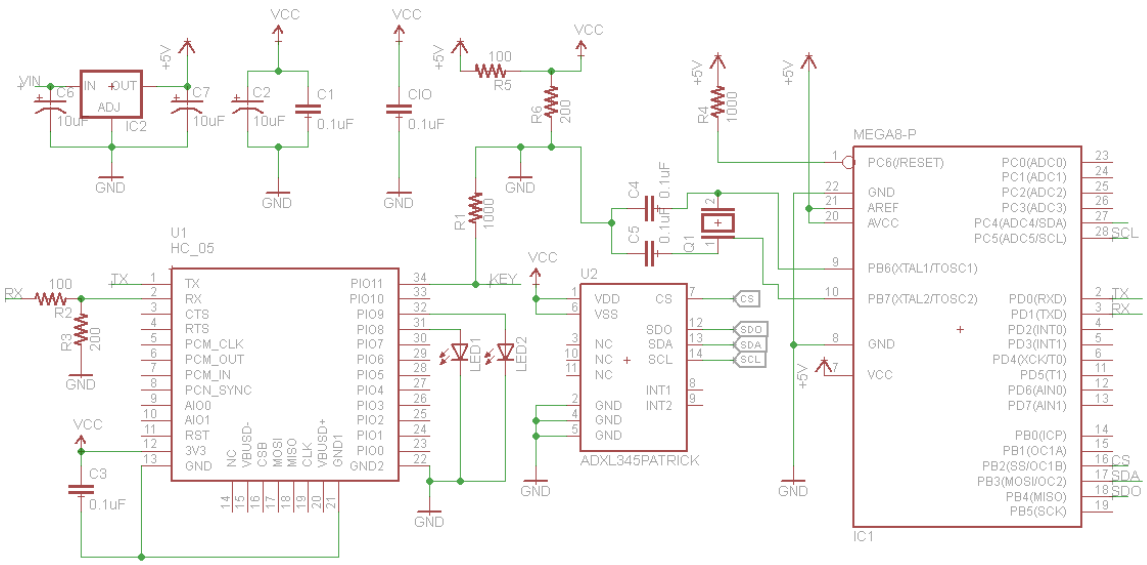

Figure 4.13 Detailed schematic of the circuit in the collar.

4.6.2 Base Charging Station

The base charging station's primary functions are to allow wireless charging of the ball, provide housing for the motion sensor, and act as the center of the play area. The basic functionality of the base charging station was shown in Figure 3.12, and the implementation of this block diagram is shown in the schematic of Figure 4.14. The power for this device is supplied by a 120V household AC power socket, and transmitted wirelessly to the ball through a WPC certified transmitter and receiver.

4.7 Power Systems

4.7.1 Collar

The components on the collar all have similar voltage requirements and total current requirements which can all be met by a single power source, a pair of AA batteries, will power the accelerometer, processor, and Bluetooth systems. The expected maximum load falls well below that maximum supply power for two series AA batteries, and the batteries can be expected to last sufficiently long.

AA and AAA batteries are the only two batteries being considered in detain for the collar because of their widespread availability and low cost. Typical AA and AAA batteries of common chemistries produce 1.5V per cell and can be connected in series to meet these input voltage specification, but the size and chemistry will affect battery life, cost, and size. Using the minimum voltage at which the device can function, 1.9V, and the service hour calculation curves for Duracell Coppertop AA [26] and AAA [27] batteries the expected battery life for

the collar can be calculated. Since the 1.9V is split across two cells, the average cell voltage must be greater than .95V. Interpolating the curve data it can be seen that the typical battery life of a pair of AAA battery would be approximately 1000 hours. Approximation of a pair of AA batteries is more difficult because lowest current measurement is at 5mA, however, by extrapolating from the given data, lifetime can be expected to be greater than 1000 hours and may approach 1500 hours.

4.7.2 Base Charging Station

The power for the base charging station will be derived directly from a household power outlet, carrying 120V AC power. This power will be stepped down using a transformer, rectified using a diode bridge, smoothed and filtered using a large capacitance and finally regulated to an appropriate voltage to be used by the components. The components to be powered include the wireless power transmitter, the motion detection subsystem, and the communications subsystem.

All components involved in the power supply must be designed to meet the maximum power requirements of the sum of all components being supplied and an additional safety margin. The wireless power transmitter will be the most significant load, and can be expected to draw a maximum of 2 amps at 3.3V. Other components will account for an approximate 100mA and the safety margin will be to round up to the nearest amp, making the nominal power requirement 3A at 3.3V or 9.9W, which will also be rounded up to 10W.

4.7.3 Ball

The power requirements for the ball are difficult to estimate because of the wide variability in power consumption of the motors. The motors selected for this project have a 200mA no load current consumption at 12V, however, testing has shown even at only 6V the current consumption can spike to 1A stall current. The expected peak torque requirement for our mechanical systems is approximately the torque produced by the 6V 1A stall current, with the typical operating power requirement being a large portion of the peak power requirement due to frequent accelerations, decelerations and sharp turns. Assuming a constant power efficiency over voltage and load, it can be expected that the current required to produce this same torque at 12V would be approximately 500mA, making the total current required by the two motors 1000mA. For the power system design, it will be assumed that this power is the maximum required by the main driving motor. The total requirements from the processor, communication, sensors, and control systems will be no more than 200mA peak when all systems are active and 100mA typical at an operating voltage of an average of 3V during normal active operation. The total power requirement can be calculated and converted to a current requirement from the 12V supply battery as follows.

$$I_{active} = 1000mA + 100mA \times \frac{3V}{12V} = 1025mA$$

This is a very rough estimate and will require verification in the testing stage. In order to accommodate the potential errors due to estimation, a large safety margin will be employed. A minimum of double the expected continuous active current, 2.5A continuous will be required when selecting the battery and power supply components, and 2A continuous for all components in the direct power flow line to the motor control. This safety margin should minimize the potential need for future redesign and minimize the potential for failure. The peak current requirements for this device should be a minimum of double the components required continuous current, mainly due to the observation that the motors appear to be operating at half of their maximum operating power and to account for the possibility that an operation requiring full power may occur, and should not cause failure of any individual component. Possible times that maximum motor power may be required are a mechanism for dislodging the device when it is found to be stuck.

In addition to the active mode, lower power modes will also be used, when the device is awake, but motionless, meaning that no power is being drawn by the motors. To calculate the expected battery life of this system, we must also know how much time this device will be used. Since this device is intended to operate during the time the owner is travelling to and from work as well as the time the owner is at work, the expected daily operation time is 10 hours. It is widely known that dogs take frequent naps and have sleep patterns that differ greatly from humans. The amount of time a dog sleeps daily varies greatly with age, breed, and most importantly, with the level of excitement of the environment, however the typical dog will spend about 14 hours every day sleeping [28]. Since dogs will sleep most of the time that the owner is asleep, it can be expected that 8 of these 14 hours every day are at night, when the device is inactive. During the time the owner is away, the excitement level of the house decreases greatly and the dog will tend sleep more. It will be assumed that the dog spends about 4 of the ten hours sleeping. In addition to the time spent sleeping, the dog will spend a large portion of its time outside of the play area, leaving the device in an awake but motionless state. If it is assumed that the dog will spend no more than 4 of the 6 waking hours in the play area, the energy capacity requirement of the batter can be calculated as follows.

$$Capacity = 1025mA \times 4h + 25mA \times (10 - 4)h = 4250mAh$$

This capacity is a rough estimate and the actual required capacity will vary greatly depending on the dog's activity level and level of interest in this device. The battery should be designed to survive the longer days and will degrade in capacity over time, so with this need to continue performing at a high level for a long period of time, the desired capacity should be about 5000mAh.

In addition to the electrical power requirements of the battery, the battery must also fit within the enclosure, along with the two motors, mechanical supports, PCB and all connected components, and any additional materials. The battery will be one of the largest and heaviest components, and can be situated in the center of the sphere if necessary to ease the size requirements. With the expected exterior diameter of the mechanical enclosure to be 6 inches, the maximum usable diameter can be expected to be approximately 5.5 inches. Using these size limitations battery size constraints can be calculated. If the length, width, and height of the battery pack are treated as mutually perpendicular vectors, the requirements for size can be described by the equation that follows.

$$\sqrt{length^2 + width^2 + height^2} < 5.5\ inches$$

This leaves a large amount of freedom in choosing a battery, but will be simplified by the standard diameter of the cells used to make up the battery which gives rise to few discrete heights, lengths and widths, depending on how the individual cells are arranged.

In order to prevent Puppy Pal from dying when it's supposed to be active, the state of charge of the battery had to be monitored. The state of charge would have been estimated by integrating the current flowing through the battery pack while charging and discharging. This value would have been measured with a current sensor. The sensor was picked initially based on the cost, current it is capable of measuring, and how the output can be connected to the microcontroller for analysis.

The current sensor ACS712 is available for $9.95. Its output is reflective of the current's behavior. A sinusoidal current results in a sinusoidal output. A DC input results in a DC output. The DC signal was used in this project. The sensor has sensitivity between 66 and 185 mV/A depending on the specific part. Only current up to 5A can be measured. To find precise values, the output signal needs to be amplified. The ACS714 can be purchased for $9.95 It has a sensitivity of 185 mV/A. This sensor is almost identical to the ACS712. Either could be purchased with the same effectiveness in analyzing the state of charge. Based on testing, the behavior of the output would have told Puppy Pal to start, continue to, or stop charging.

4.9 Ball Schematic

The design of the ball will be structured around the C2000 family of MCUs from Texas Instruments. There are two UART ports, which are 2 RXD and 2 TXD pins that can be used for the two separate wireless modules. Figure 4.14 illustrates a detailed schematic of the core design that will be used for the ball. In addition,

there are multiple PWM pins that can be used to connect to the motor control subsystem.

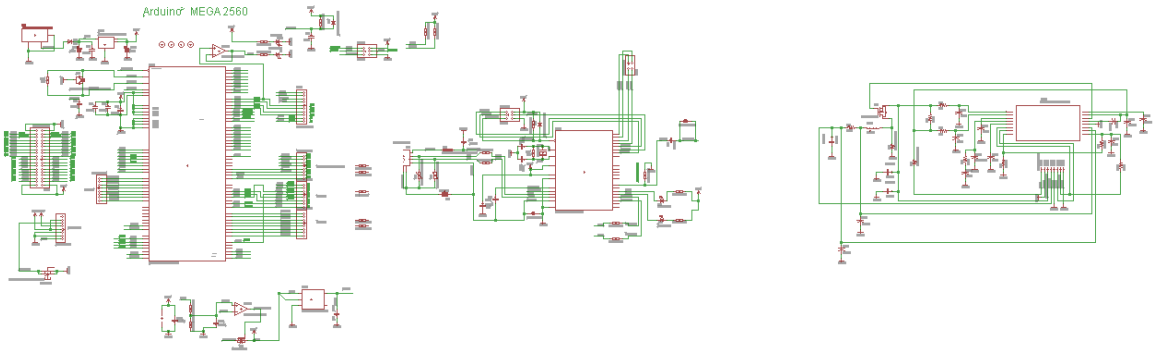

Figure 4.14 Ball MCU schematic

5 Design Summary of Hardware and Software

5.1 System Overview

As mentioned before, the system has two main modes; autonomous mode, which operates the motors in the ball automatically and remote control mode, which provides the user with an override to control the motors and other features in the ball manually. In remote control mode, the user is in full control of the mobility, triggering the sound subsystem, and turning the Puppy Pal on or off. Control of the Puppy Pal is dependent on many factors. When the ball is under remote control and the user becomes unavailable, the system is triggered to autonomous mode. The system will be designed assuming the control is primarily to be in autonomous mode most of the time. When it is not being control manually or in autonomous mode, it is in sleep mode. When in autonomous mode, the system checks if there is a substantial amount of battery left. If the system needs to recharge, it departs to the charging station then enters a low power sleep mode until the battery is recharged to a specific amount. If the battery is charged to the point where the system can function properly, then the system checks if the motion from the dog has been detected. If the system does detect motion over the threshold value, it will operate the motors, if not, the system will enter sleep mode to conserve power. Figure 5.1 illustrates a flow chart of the system overview the Puppy Pal.

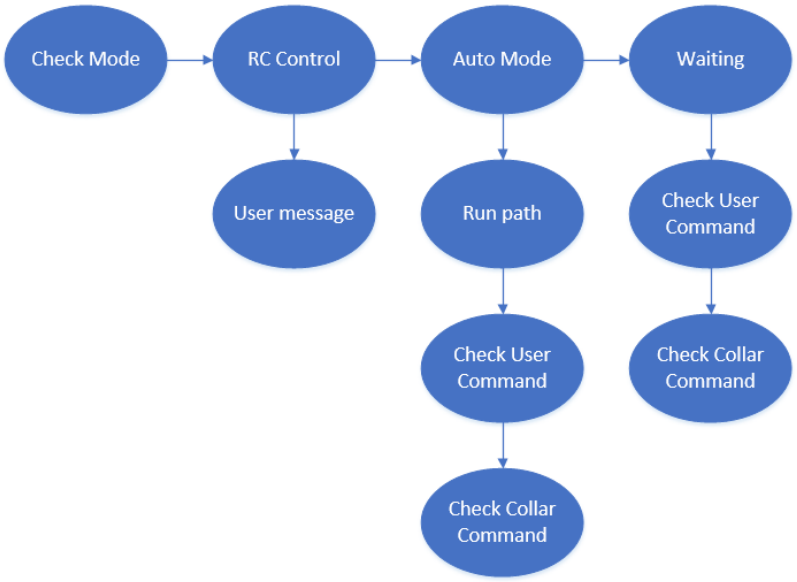

Figure 5.1 System overview flowchart.

5.2 Mechanical Housing Design Overview

Three mechanical housings will be used in the total system comprising Puppy Pal. All three of these devices will be subject to harsh conditions, including moisture, dirt, dust, and even regular chewing. These housings will also contain sensitive electronics which must not come into contact with any of these elements, despite the efforts of a curious dog.

The housing and cable connections for the base charging station are important because this is the portion of the system which is connected to the high power household outlet. The dog must never have any opportunity to come into contact with these wires under any condition, therefore, the power will be immediately stepped down to a lower voltage, which would be nonthreatening to a dog's safety, for cable connection to the actual device. Despite the precautions taken to ensure safety, in the event that the dog tries to chew the cord, additional measures should still be taken to ensure that the dog doesn't have the access to the cord. Since dogs tend to be curious and investigate by chewing, this cable should be protected by a durable and difficult to dislodge cable cover, minimizing the potential for damage to the system. The actual mechanical housing for the base charging station should also be difficult for the dog to grip, by using hard, smooth materials and soft edges. The material must not interfere to any significant extern with the wireless power transfer from the base charging station to the ball, meaning that the enclosure cannot be metal. The previous design requirements suggest a durable plastic would suffice, and also be readily available in multiple shapes and sizes. The electronics should be located off of the ground to avoid standing water that may occur during rains. The housing should also have a mechanism for securing the position of the ball in a manner that maximizes the efficiency of the wireless power transfer. The housing must also house the proximity detecting subsystem. This will require a slightly taller portion of the system in order to see over obstacles on the floor, and may still be situated inside a plastic enclosure with suitable transparency to infrared light.

The housing for Puppy Pal is also very important because it is actually intended to be used both inside and outside, knocked around, and chewed on by a dog. Some dogs have extremely powerful jaws, capable of bite forces of over 4000 Newtons (900 pounds) at the molars and over 1000 (225 pounds) Newton at the Canines [29]. Bite forces in this range are very capable of breaking plastic enclosures. Large dogs have snout lengths of approximately 6 inches, and can open their moth approximately 75 degrees, allowing them to grip a ball of about 7.5 inches in diameter in the very tip of their mouth. This will allow large dogs to pick the ball up, however, at the tip of the snout, the bite force is diminished as seen by the trend from molar bite force to canine bite force. By using a ball with a diameter of 6 inches, the forces that the ball will be subjected to can be greatly decreased, therefore increasing the durability of the ball. This design must also be of withstanding the elements, regular chewing, and forceful impacts caused by rough play. Ideally this device would be placed inside a fully enclosed plastic

ball, however this causes difficulties with maintenance and may not be feasible. Other options include a ball that screws together with watertight sealing tape wrapped around the threads, or a fluid seal such as silicone or certain types of glue. Since this device is meant to simulate a living animal with which the dog can play, the ball's mechanical housing will be covered in fabric mask. The fabric mask will not be nearly as durable, and will need to be replaceable. This mask can be designed to look like a number of animals which will work to spark the dog's interest and will provide something to grab and play with, simulating the feelings a dog typically experiences when nipping at a play mate. Masks will have an opening, in which, the ball will rest and a strong Velcro strip to secure the ball inside. It is anticipated that this fabric cover may have an effect on the mechanical responses, but this will be minimized and accounted for during testing, and is not expected to pose a problem.

The housing for the collar requires a watertight seal, and a compartment which can be opened to change the batteries, eliminating the possibility of a fully enclosed device. The method for sealing this device will be a watertight gasket around the battery compartment, in addition to fluid seals around the battery compartment, providing two levels of redundancy to minimize the possibility of failure. This device must also be small enough to fit on a typical dog collar, without causing any kind of discomfort. A typical dog collar measures 1 inch wide, and the device should be designed to be of similar width. The length, effectively the circumference of the dog's neck, varies widely from breed to breed, and can range from 6 to 40 inches. The curvature of the collar when worn will be the limiting factor for the collar, though the smallest dogs could potentially wear the device attached to a harness. The limit for the height of the device is the most undefined, however the height must be minimized to avoid the dog knocking into things it otherwise wouldn't. The device should be designed to provide no discomfort to small dogs, but also withstand being laid on by the heaviest dogs, meaning the package must be very durable. This mechanical housing must have a secure method for mounting the PCB in order to minimize unnecessary vibrations which will add noise to the accelerometer and potentially cause false triggers which lower battery life.

5.3 Software Overview

The Software Overview section of this documentation provides an insight into the brains behind the Puppy Pal, collar and Android devices. All classes talked about are described in detail, but it is not necessarily true that all classes are mentioned. There are many instances of a base class being inherited by many other classes that would be redundant to talk about. All classes are shown in the class diagram however. The first section of the software overview will explain the software on the Puppy Pal device, whose class diagram is in Figure 5.2.

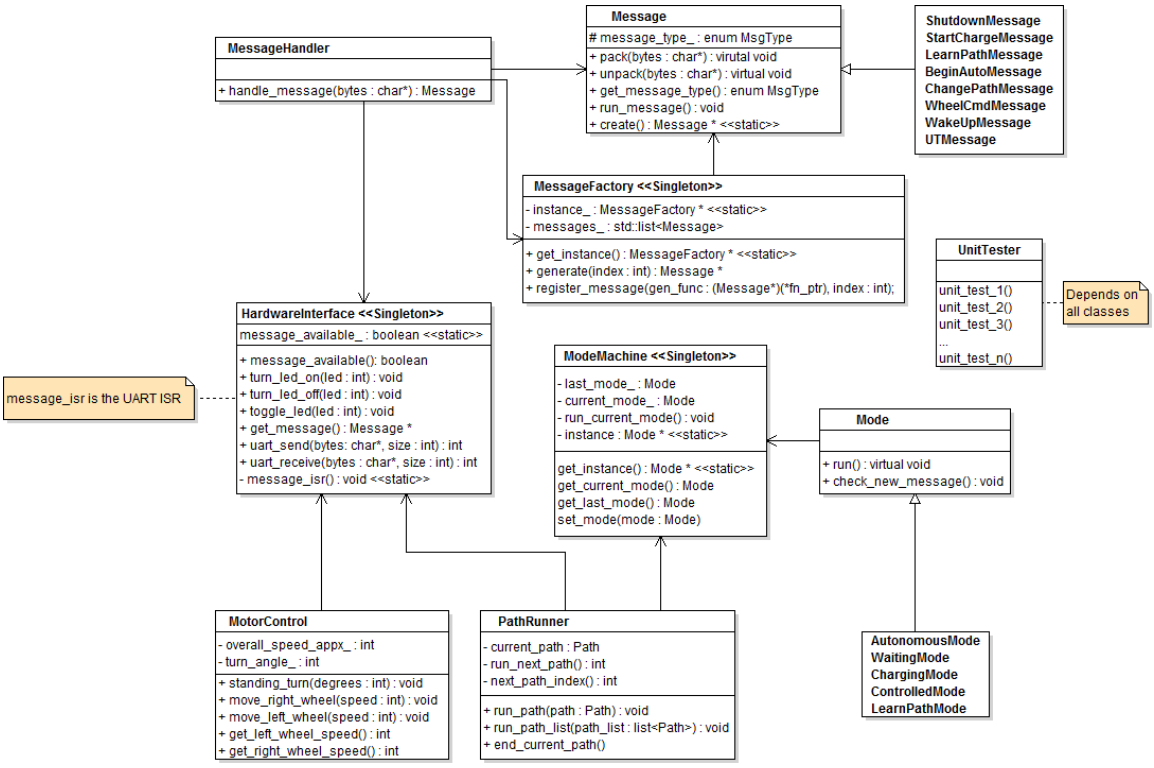

Figure 5.2 Puppy Pal software class diagram

Hardware Interface: The HardwareInterface class provides an easy-to-use means of accessing the hardware of the microcontroller. From a user's standpoint, this makes the code easier to use and read. From a performance standpoint, the code will be less prone to error and easier to trace problems because of the overall modular effect this puts on the code. The class implements the Singleton design pattern to ensure that two or more areas of code are never trying to access the same data with different objects. The class's public data members are shown in the class diagram (Figure FIG#) and of the most important of the list is the private static interrupt member function uart_interrupt(), which is the interrupt service routine for UART (SCI) data transmissions. A private member boolean value will be set upon the execution of the this ISR, which is checked in each modes (see Mode class) at the beginning of its execution loop. This is the basis of the messaging system, which controls the actual functionality of the system.

Message: The messaging system is unknown at the communication level of our system. A sequence of bits is sent over Bluetooth and a serial communication connection, but until the bits are decoded they are meaningless. The *Message* base class provides an abstraction of these bits into a concrete data type that knows how to handle itself. The class definition provides three abstract member functions that are to be defined by all inherent classes. The first, *pack*, takes a sequence of bytes and the number of bytes as arguments, and fills out the the class that it is called upon based on the information in the bytes. The second,

unpack, is similar, just in the reverse order. The third, *run*, actually executes what the message is intended to do. For instance, if a message is received to change the mode, the messages run member function should get the ModeMachine (see ModeMachine class) instance, and set the current mode to the one that was transmitted in the message. The advantage to this design is clarity: assuming the *pack* function is implemented correctly, the class will contain all the correctly filled out data fields to implement its job. There are many other classes that inherit this base class, but it's not necessary to go into detail about them.

Message Factory: *MessageFactory* is a simple class that holds all the available message types. There only needs to be one instance of this class, so it implements the Singleton design pattern. All messages are associated with a number, and by calling this class's main member function, *generate_message*, you will get a new message of the type that corresponds to the integer value passed to it. This class isn't a factory in the classical sense of the pattern, but it does provide an easy way to generate messages, which will clean up code and make it easier to read and use.

Message Handler: *MessageHandler* is a simple class solely devoted to servicing new messages that come into the system. It has only one public member function: *handle_message*. Other than being intuitive to think about, this class cleans up code by encapsulating redundant commands that will be implemented in every mode's main functionality.

Mode: Modes define a major state that the system can be in (See Modes section of software overview). To be in a certain mode means that you are telling the system to behave in certain way, and the *Mode* base class is the basis for all of them. For all intents and purposes, this is essentially the main loop of the system. With that being said, it is important that they have graceful exits to avoid unrecoverable system errors.

Mode Machine: The *ModeMachine* acts as a parent object to the system. It has a simple task of switching to and running modes. Mode change messages come from two sources: the collar device or an Android device. The collar can only send two mode change messages, namely AUTO and WAITING (see Modes section of Software Overview). The Android device has the unique ability to send the device into any mode of its choosing. On one hand, this allows the user to choose if he wants to control Puppy Pal or wants the device to run on its own. On the other hand, from a developer's standpoint, we can quickly test many aspects of the systems design, including message sending and mode changes. This greatly eases the debugging and testing portions of the development of the system. Upon a mode change, the previous mode of the system will be stored. In the case of an error occurring during a mode change, the previous mode will be reset and run. Changing modes is the most critical aspect of the system, and therefore, when errors occur, they must be handled in the most graceful way

possible. If a drastic mode change error occurs that does not allow us to recover, the system must do a hard reset.

Path Running: When the system is in autonomous mode, it will be running a predefined set of wheel commands. *PathRunner* holds all of these wheel commands in an indexable vector. Of its more important member functions, *run_path,* which will be overloaded to take an integer index or an actual Path object, will be the most used. The class also contains a flag that allows for sporadic or regular interval changes in the currently running path. This is passed in by the Mode change message that tells the system to go into autonomous mode (See Messaging System section of Software Overview).

Motor Control: We will primarily be using a set of libraries called instaSPIN from Texas Instruments to control the motors for testing purposes in the development stages of the project. Aside from InstaSpin, this class will interface heavily with the *HardwareInterface* class and will only be used when in the AUTO or PHONE modes. *MotorControl* will basically be an abstraction to the users for basic motor commands like still turning left and right, move forward at a certain speed, and turning, which is basically changing the wheel speeds independently to create a slight offset.

Motor: The *Motor* class will provide an software abstraction interface for a physical motor. Since motors are technically controlled by a PWM control line on the microcontroller, the *Motor* class will hold this information, as well as its current PWM voltage, which will also provide a rough estimate of the speed of the wheel is moving. The *MotorController* will be composed of, in the case of the Puppy Pal, two *motor* objects to command.

UnitTester: Testing will be done through a special class designed solely for running all available unit tests. The class will be static and only compiled into the program when UNIT_TEST is defined. The class consists of only static member functions, each of which has a special define that should be set if that unit test is to be run. When unit testing is enabled, the *UnitTester* class will take over the main functionality of the program. After the unit test has completed, the system resumes its norming operation by instructing the system to go into WAITING mode (see modes section of Software Overview). From here, the system waits for input from either the collar device or an Android device.

Class Name	Brief Description	Special Attributes
HardwareInterface	Provide an abstraction between microcontroller hardware and programmer	• Singleton • Static interrupt member function
Message	Base class for all messages sent and received by system.	• Abstract base class
MessageFactory	Generates messages based on message type number.	• Singleton
MessageHandler	Gets, unpacks and runs messages when they arrive.	• None
Mode	Generates messages based on message type number.	• Base class
ModeMachine	Handles switching between system modes	• Singleton
PathRunner	Handles running paths when in autonomous mode.	• None
MotorController	Interface to all motor commands.	• None
Motor	Controls a single motor	• None
UnitTester	Holds and runs all unit tests	• Static • Only run in unit test mode

Table 5.1 Summary of Puppy Pal software main classes

5.3.1 Android Device

Next, the Android device software for controlling the Puppy Pal. The requirements state that a path shall be able to be drawn for for the Puppy Pal to follow, as well as be able to freely control the device without the aid of predefined paths. There are two major options when it comes to graphics in Android programming: android.Graphics and OpenGL, or, more specifically, OpenGL ES, the embedded systems derivative. OpenGL is a proper graphics library with almost endless amounts of options to configure. The controller is really simple however, and only a simple path needs to be drawn at a time, so Androids built in graphics libraries will be sufficient. The class diagram for the application is show in Figure 5.3.

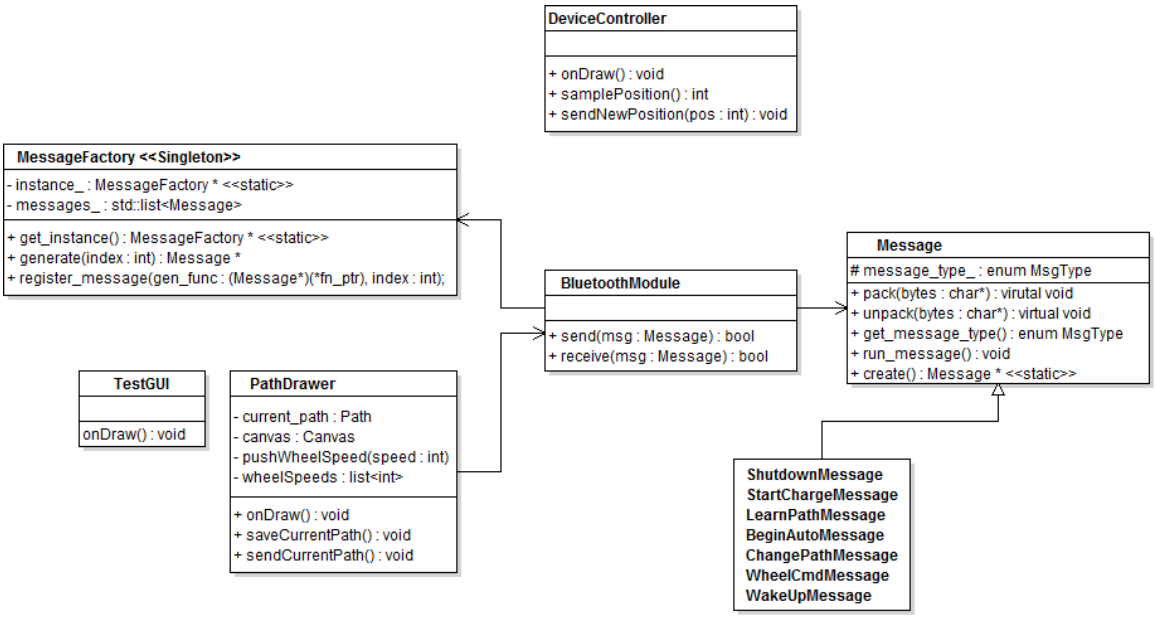

Figure 5.3 Android software class diagram

Message Factory: This class is essentially identical to the *MessageFactory* class inside the Puppy Pal device. Messages must be consistent no matter the source that they come from. This also becomes important because the android device is the main source of sending debugging information and just testing the system out as a whole.

Path Drawer: To provide a nice user interface, the user will be able to draw paths for the Puppy Pal device to save off and run later. This class will handle all of the drawing and creation of path data to be sent off to the Bluetooth module to be stored on the Puppy Pal device. Paths will have a limited size and be sent in a special way: first the Android device will issue a command to change to LEARN_PATH mode. Then a path start message will be sent and stored. When the device acknowledges the message and sees that it is ok, it sends back a message informing the Android device to send the next message. If the message fails a message is sent back to alert the Android device that an error occurred and the message needs to be resent. Finally a trailer message followed by a Mode change message to go into the previous mode finishes the transmission sequence.

Device Controller: This class is very similar to the *PathDrawer* class except that the finger movements will not be drawn, and the messages are blasted from the phone to the Puppy Pal device. This is the main class that makes the device roll from the user controlled point of view. Because we want the device to respond as quickly as possible, the messages are sent in a very “UDP” like fashion. In the case that a bad message is interpreted by the Bluetooth receiver, it will simply be disregarded and prepare for the next message to arrive. This is the main class

and its GUI interface is the first thing that the user is greeted with upon opening the application. All other functionality (GUI interfaces) will be held in menus.

Bluetooth Module: Bluetooth data can be accessed through a number of Bluetooth libraries made available in the Android APIs. This data is encapsulated into a class to make sure that sending and retrieving Bluetooth data is abstracted to the point of knowing about System messages and the errors they can contain. Messages will eventually get to the point where they are handled the same way as on the Puppy Pal device.

TestGUI: This class provides a simple view of the output of unit tests on the Puppy Pal device. It is arranged into an Nx2 table, where N is the number of tests. The first column is the test name and the second column is the text “Pass” or “Fail.” Tests on the Puppy Pal can also send extra information about the test. By clicking the name of the test a second menu pops up and displays the information. This is done mostly for clarity, because more test do not have extra information than do.

Class Name	Brief Description	Special Attributes
MessageFactory	Generates messages based on message type number.	• Singleton
PathDrawer	Draws the path that a user is dragging with his finger.	• None
DeviceController	Controls the Puppy Pal device from the Android Phone	• None
BluetoothModule	Handles sending and receiving Bluetooth Messages	• None
TestGUI	Shows Puppy Pal’s unit test output	• None

Table 5.2 Summary of Android software main classes

5.3.2 Collar

Because the collar is such a simple device, the software will be written in pure C. The only task this device has is to check the accelerometer within the collar and send a message, which will always be the same, to the Puppy Pal device. All other processing from this point in time is being done on the Puppy Pal. A few helper functions are created to interface directly with the hardware and make the code cleaner and easier to read.

5.3.3 Messaging System

Bluetooth message are two bytes wide, with the first four bits indicating the message type, and the last twelve bits being the payload. The general form is shown in figure 5.4. Message correctness is very important. When messages arrive in the microcontroller, they will be sent straight to a message handler that unpacks its data and handles it appropriately. There are many messages coming from different sources that may arrive at the same time, and so bad messages can happen at any time. However, the execution of code inside the microcontroller is very time sensitive and cannot waste clock cycles handling bad messages, so it is critical that when messages come in they are valid and able to be processed. Parity bits will be used to assure message integrity. When bad messages arrive, a signal will be sent back to the sender and inform it that the message needs to be sent again. This happens for both the Bluetooth and the UART communication between the Bluetooth device and microcontroller. Because of the small amount of information we are sending at a time, a baud rate of 9600 will be used. This speed is plenty fast, but also slow enough to have minimal errors during transfer. Specific system message are shown in the diagrams below, with the message type bit layout and description preceding the payload layout.

Figure 5.4 Generic message layout

Wakeup: The system has two major states that it can be in: active or non-active. The transition from non-active to active can happen by a user sending this message from an Android device, or the collar of the dog broadcasting this message because it knows the dog wants to play. If the system is in an active state and this message is received, it is ignored to prevent unnecessary computations while the device is running. The first two bits of the payload represent the sender of the message. Possible combinations are 00 for the phone and 11 for the collar. Bits 9 - 0 are unused. Figure 5.5 shows the bit layout for this message.

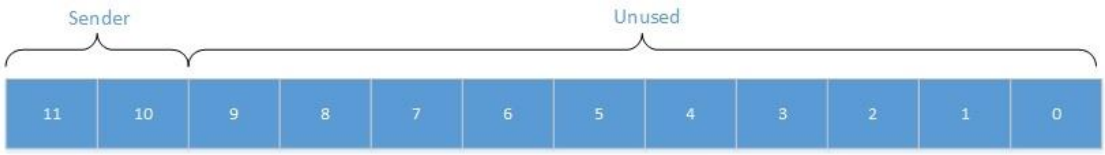

Figure 5.5 Bit layout of wakeup message

Shutdown: The opposite of the wakeup message. This instructs the the system to go into its lowest power state and wait for other input. If no input comes, the

system assumes the dog is done playing and sets itself into RETURN_BASE mode. The only thing that matters about this payload is the message type. In other words, the payload is empty. Figure 5.6 shows the bit layout for this message.

Figure 5.6 Bit layout of shutdown message

Startcharge: This message instructs the system to go into a low power mode and begin wireless charging. The difference between this message and the shutdown message is that this is that this message only waits for input from either an Android device or the dogs collar. The system will never instruct to go anywhere because it is already at its charging station. There are no significant bits in the payload. Figure 5.7 shows the bit layout for this message.

Figure 5.7 Bit layout of startcharge message

Beginauto: As per the requirements, the system has two major modes it can be in while running autonomously: RANDOM and PATH. The beginauto message simply instructs the system to first go into autonomous mode, and then one of these submodes. This message can only be sent by an Android device. The first two bits of the payload indicate which autonomous sub-mode to put the system into. These can be either 00 for RANDOM or 11 for PATH. Assuming it is path mode, the next two bits specify how the paths should execute. These can be 00 for a single path to run, 01 for all paths to run sequentially, and 10 for all paths to run in a random order. Finally, assuming that 01 or 10 was specified for bits 9 - 8, bits 7 - 3 indicate the time, in seconds, each path should be run before switching to the next path. This allows a range of 0 to about 30 seconds for each path, but a minimum time of 5 seconds is required for this value. Anything less than 5 is defaulted to 15 seconds. Figure 5.8 shows the bit layout for this message.

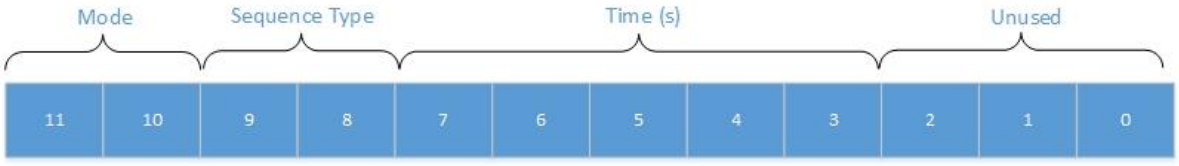

Figure 5.8 Bit layout of beginauto message

Learnpath: A user can specify custom paths via the Android device. When the path has been finalized and is ready to be sent to the Puppy Pal device, the Android system first sends this message, indicating that the system should get

ready to receive a set of WHEEL_CMD messages (see wheelcmd section of Messaging System) to save and store in a given index. The significant bits of this message are 11 - 9, which represent an integer index to store the path inside the Puppy Pal device. Figure 5.9 shows the bit layout for this message.

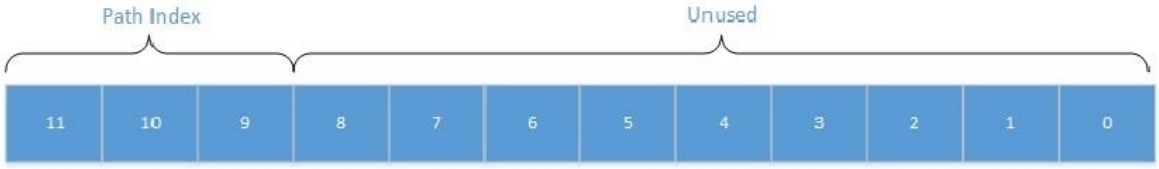

Figure 5.9 Bit layout of learnpath message

Changepath: If the system is in autonomous mode, change the currently running path to whatever path exists at the given index. Much like the learn path message format, bits 11 - 9 of this message indicate an integer index to find the path to run. Bits 8 - 0 are unused. Figure 5.10 shows the bit layout for this message.

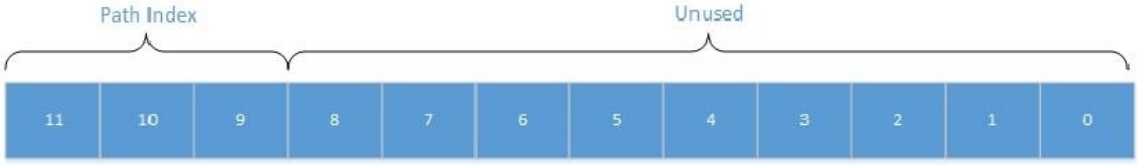

Figure 5.10 Bit layout of changepath message

Wheelcmd: Arguable the most important data an Android device can send, this message indicates how to change the speeds of the wheels while the device is in PHONE mode (see Modes section of software overview). When the phone is sending a pre-planned path to the Puppy Pal, it is also just sending a sequence of wheel commands for the software to store as a list. Bits 11 - 6 represent a signed right wheel speed, and bits 5 - 0 represent a signed left wheel speed. Figure 5.11 shows the bit layout for this message.

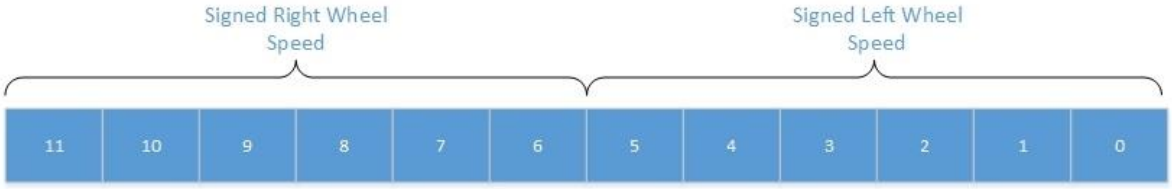

Figure 5.11 Bit layout of wheelcmd message

utmessage: This message is used for communicating unit test information between the Puppy Pal device and the Android software. Each unit test in the unit test software is assigned a test ID which is represented in the payload as bits 11 - 7. Bit 6 represents a 1 for pass and 0 for failure. Bits 5 - 0 are extra information that the test might want to convey. It is left up to the specific unit test to decode this section of the payload. This also implies that the Android software must have knowledge of the unit tests so it may decode the extra information on the phones end. Figure 5.12 shows the bit layout for this message.

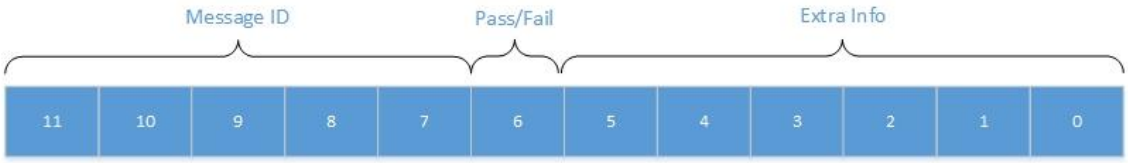

Figure 5.12 Bit layout of utmessage message

Message Type	Brief Description
0000	Wake the system up from its low power, “sleep” state.
0001	Go into low power mode. The system is not functioning.
0010	Interrupt the system and tell it to start charging.
0011	Set system mode to autonomous movement.
0100	Set system mode to learn a path.
0101	Change the currently running path.
0110	Change wheel speeds.

Table 5.3 Summary of system messages

The overview of the Dog Collar system is shown below in the following flow chart. It is a visual of the algorithm used to send the device into Autonomous mode. In a brief explanation it just states if a ADXL 345 threshold has been met, it sends the Puppy Pal to move, if not it sends the Puppy Pal to waiting.

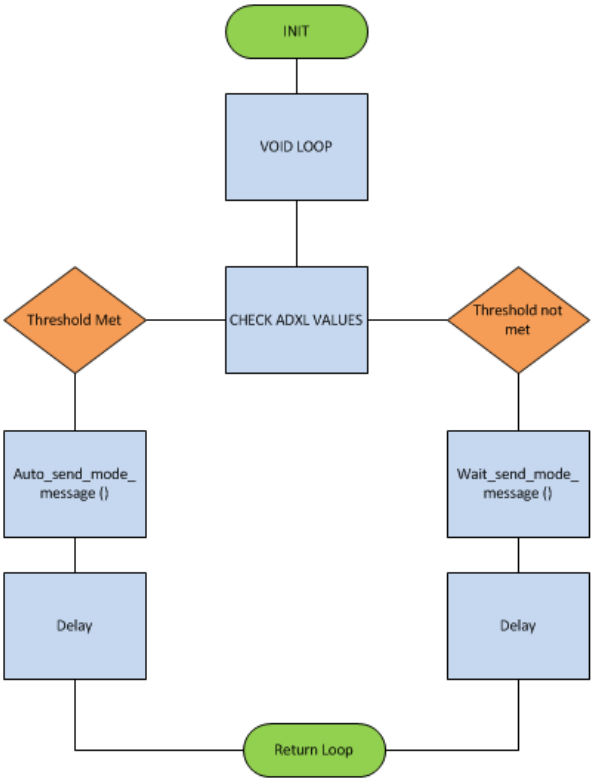

Figure 5.13 Flow Diagram of Dog Collar software

5.3.4 Bluetooth Communications

Bluetooth messages can come from two sources: the collar of the dog, or an Android device. The diagram above explains the flow of Bluetooth communications from inside the Puppy Pal device. When a Bluetooth message is received, it sets pin1 on the device high. A valid message that is received is sent to the microcontroller via UART, which an interrupt is tied to, so that when it goes high, an ISR sets a boolean value in the code that indicates that a new message has arrived. Messages are two bytes a piece, but data is sent over Bluetooth one byte at a time. To get around having to deal with this in the microcontroller's code, the (PART#) Bluetooth receiver being used is programmable and will act as a buffer, setting its pin high only when a valid message has been received.

5.3.5 Modes

Modes represent a certain state that the Puppy Pal device is in. To be in a certain mode means to behave in a certain way. The Puppy Pal device can be five different modes: PHONE, AUTO, CHARGING, WAITING, and UNIT_TEST. PHONE means that the system is completely controlled by an Android device. The Android device can send it commands to move, learn a path, go into an autonomous mode, or shutdown. As per the requirements, this mode cannot be

interrupted by other components of the system, such as the dog's collar. It may help to think of this mode as the master, and all other modes are slaves. AUTO mode means that the system is running autonomously, *how* it runs autonomously is still up to the user, however. There is a choice of running randomly, a single path, or all paths. When running randomly, the device makes sporadic turns in all directions in random intervals of time. When running a single path, the device will follow a user defined set of coordinates until the device is low of battery, the dog leaves the play area, or the system is interrupted by a message sent from an Android device. The last of the autonomous modes is to run all the paths. This can be done in two ways: randomly choosing a path, or running paths in order. In both of these choices, the user sets a time delay designating the amount of time, in seconds, to run a path before changing to the next. CHARGING mode is simple: the system is in it's lowest power state, and assumed to be on it's wireless charging station. The system waits for messages to come in, and any message that is received other than START_CHARGE (See Messaging System of Software Overview) will put the system into some active state. The system can be interrupted by an Android device or the collar device. WAITING mode is quite similar to CHARGING, except that the system is not in a lower power state to begin with. It is assumed that if you're in this mode, either the collar or the Android device will be giving the system input. UNIT_TEST is a special mode that is only available when the system is compiled with unit testing enable. During UNIT_TEST mode, no external input can be received unless it is required by a test. All enabled unit tests will run, and unless a critical system error occurs, the system will resume normal operation upon completion. During tests, the device will broadcast messages that can be picked up on an Android device. The first message indicates that testing will be begin, and sends the Android device into a "test output" screen. From there, the messages are decoded and displayed on the Android device, and indicate a pass or fail for a given test.

5.3.6 Environment and Coding Standards

Development will be done on a PC running Windows. Compilation and loading of the code into flash will be handled by Code Composer Studio v5. Version control will be done with Git. There will be a main branch, and new features will all fork the main branch, be implemented, and then merged to minimize conflicts. Code documentation will be done by Doxygen with its default tags. All classes and member functions should provide a brief explanation of what its purpose as well as an explanation for all arguments and its return value. A detailed explanation can be added under the brief one if necessary. A small set of coding standards is shown in the table below.

Object	Description	Example
class name	camel casing, starting with capital letter	class MyClass { };
member function	all lowercase, words separated by underscore	void member_function(int x);
private member variable	all lowercase, words separated by underscore with trailing underscore	int private_member_variable_;
public member variable	all lowercase, words separated by underscore	int public_member_variable;

Table 5.4 Table of coding standards

6 Prototype Construction and Coding

6.1 Parts and Acquisition

Each of the subsystems that made up Puppy Pal consisted of various parts and components that needed to be collected before they could be combined. The list of materials for the project was organized by subsystem. Where the parts were meant to be ordered from will also be identified.

6.1.1 Mechanical Subsystem

The mechanical system consists of the framework, motors, sensors, and controller. The chassis for a spherical robot is not readily available for purchase, so the framework inside of the enclosure was constructed by the group and an outside party. There are multiple metal shops in Orlando that were considered for building the framework. The financial cost of having the frame custom built was not worth the time and effort that was spent being assembled by the group, none of whom had any experience metalworking. The ends of the axle were to be welded to hubs attached to opposite ends of the ball. Along the axle, a platform was going to house the PCB. Leading from the platform, a steering arm extended to the bottom of the ball. A servo would have been attached here to guide the arm. At the end of the arm laid the drive motor, the wheel, the batteries, and the charging circuit. The motor and the wheel were going to be used to drive Puppy Pal's motion. The batteries needed to be at the bottom to pull the center of mass further below the center of the ball and in order for inductive charging to occur. The wireless power receiver was also be part of the assembly.

The center of the structure actually constructed was a cube made of aluminum made by a metalshop. This cube had screws extending from five of its sides. Along these screws, springs were placed. On top of the springs, plastic bumpers were left. Together, the cube, springs, and bumpers acted as a bumper system. As the ball rolled, the bumpers prevented the internal structure from striking the sides of the ball and anything from hitting the PCB. The springs gave the bumpers flexibility for varying amounts of force.

The drive motor originally purchased was the RP6858. It was purchased in the Winter Park hobby shop, Skycraft Parts & Surplus. There was not a practical way to attach the motor to a shaft and wheels, so a gearbox was incorporated into the design. The servo was the HS-422 Servo Motor. It only needs 6V of power and was slower than the drive motor. The part was going to be ordered from RobotShop Distribution Inc. The wireless power receiver is BQ51013B. It was sampled from Texas Instruments. The 6V voltage regulator purchased was TI's TLV431x. It is adjustable between 1.24 and 6V. The original mechanical

subsystem required two of this regulator: one to power the servo at 6V and one to power the gyroscope, accelerometer, and microcontroller at 3.3V.

The gyroscope was the L3GD20H. It was available from Pololu Robotics & Electronics. The accelerometer was the ADXL335 from SparkFun Electronics. These suppliers do not provide free samples, so only two of each sensor were to be purchased. An encoder was not included in the parts list because of the Piccolo microcontroller's software making it possible to estimate speed and angular position without feedback. The TMS320F28069MPN microcontroller was going to be sampled from Texas Instruments if no cap on sampling was applied to the group's account.

6.1.2 Collar Subsystem

The collar subsystem consists of a Bluetooth chip, an accelerometer, a voltage regulator, and the ATmega328p microcontroller. The HC-05 was used to transmit messages to the ball . The HC-05 was bought on ebay for five dollars. The accelerometer was the ADXL345 from SparkFun Electronics. A pair of the sensor was sampled from this supplier. The HC-05 and ADXL345 could both be powered with 3.3V. The voltage regulator to be connected to the devices was the LM7805. This part is available for sampling from TI as well. The table below displays the BOM for the dog collar subsystem.

Discription	QTY	REF DES	Mfg P/N	Distributor	Distributor P/n#
CAP ALUM 47UF 25V 20% SMD	2	C3,C4	EEE1EA470WP	DigiKey	PCE3908TR-ND
CAP CER 22PF 50V 5% NP0 0603	2	C1,C2	C0603C220J5GACTU	DigiKey	399-1053-1-ND
LED GREEN CLEAR THIN 0805 SMD	1	LED2	LTST-C171GKT	DigiKey	160-1423-1-ND
RES 100 OHM 1/10 W 0603 SMD	1	R1	RC0603JR-07100RL	DigiKey	311-100GRCT-ND
RES 200 OHM 1/10W 5% 0603 SMD	1	R2	RC0603JR-07200RL	DigiKey	311-200GRCT-ND
RES 10K OHM 1/10W 5% 0603 SMD	1	R3	RC0603JR-0710KL	DigiKey	311-10KGRCT-ND
RES 220 OHM 1/10W 5% 0603 SMD	1	R4	RC0603JR-07220RL	DigiKey	311-220GRCT-ND
Breakaway Headers	1	AXL,BT_MOD,VIN		SparkFun	PRT-00116
ATmega328p DIP SOCKET	1	ATMEGA328P-PU		SparkFUn	PRT-07942
Lin Voltage Regulator	1	IC1		Pre-Owned	
16 Mhz Crystal	1	Q1		Preowned	

Table 6.1 Bill of Materials for Dog Collar

6.1.3 Base Charging Station

The charging station consisted of a transformer, basic electronic components, a regulator, a wireless power transmitter, PIR sensors, and a Bluetooth SoC. The 120V / 12V transformer, Y8848-AL, was be sampled from Coilcraft, Inc. Resistor, capacitors, and inductors were purchased along with the PCB. Another CC2541 Bluetooth SoC was purchased from TI for this system.

6.2 PCB Vendor and Assembly

There were two PCBs designed; one for the ball and one for the collar. Since ideally each PCB will be generally be small in comparison to most designs, all three designs will be attempted to put on one board. No conductive connections between the two separate designs were made in order to remove disturbances. Once the PCB arrived, it was separated into the three separate components. The PCB for the ball was approximately not larger than 5 inches in length and width to fit inside the 6 inch radius plastic enclosure. The PCB located on the collar is around 1 inches in length and 0.5 inches in width so it was able fit inside a small enclosure to be easily attachable to a dog's collar.

The PCB vendor that is chosen is using Advanced Circuit at 4pcb.com. This specific vendor has special discounts for college students and offers a fast delivery options if needed. One of the specials offered for students is a 2-layer PCB design for 33 dollars each up to 60 square inches. This should be enough to include all three PCB designs on one board.

Since the majority of the components used are small, surface mount components. It was needed to be assembled professionally. Many options were available, such as getting assistance from the UCF Radio Club. The UCF Radio Club will be able to give assistance by either giving donations to club for assembly or providing tutorials on how mount the parts. Another option is to find a local pick and place to assemble the board, by providing the recommended files and components to assembler services. The dog collar PCB was hand soldered from a personal acquaintance from the one the group members and the ball PCB was sent to QMS. The figure's below show the PCB layouts for the ball and the dog collar.

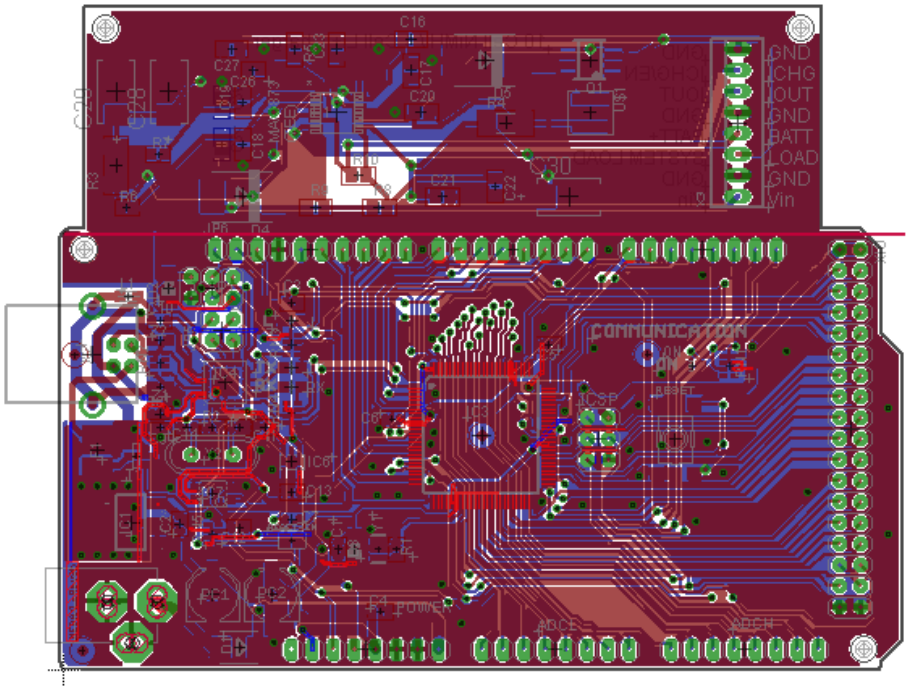

Figure 6.1 Ball PCB

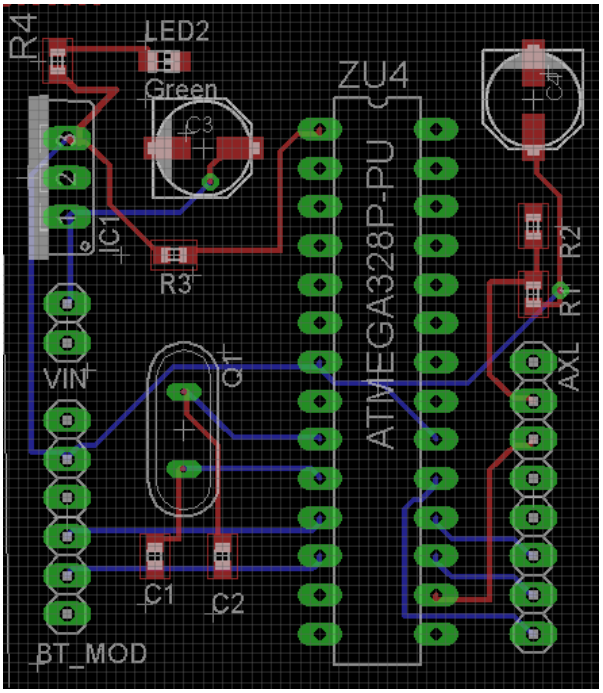

Figure 6.2 Dog Collar PCB

6.3 Final Coding Plan

The Software Overview section of this document explains in detail what individual classes are accomplishing, and gives a brief look into the system's different modes and message types. This section of the document will sum all of this up and explain what the software is doing from a simplified, top-down approach.The Puppy Pal's general flow of the software is simple: run a current mode and always check for new messages on every iteration of that mode. If a new message arrives, handle it, otherwise, continue running the current mode. From a starting point of the system being "asleep," that is, in its lowest power state simply waiting for messages instructing it what to do, figure 6.1 illustrates the flow of execution to the time a shutdown message is received.

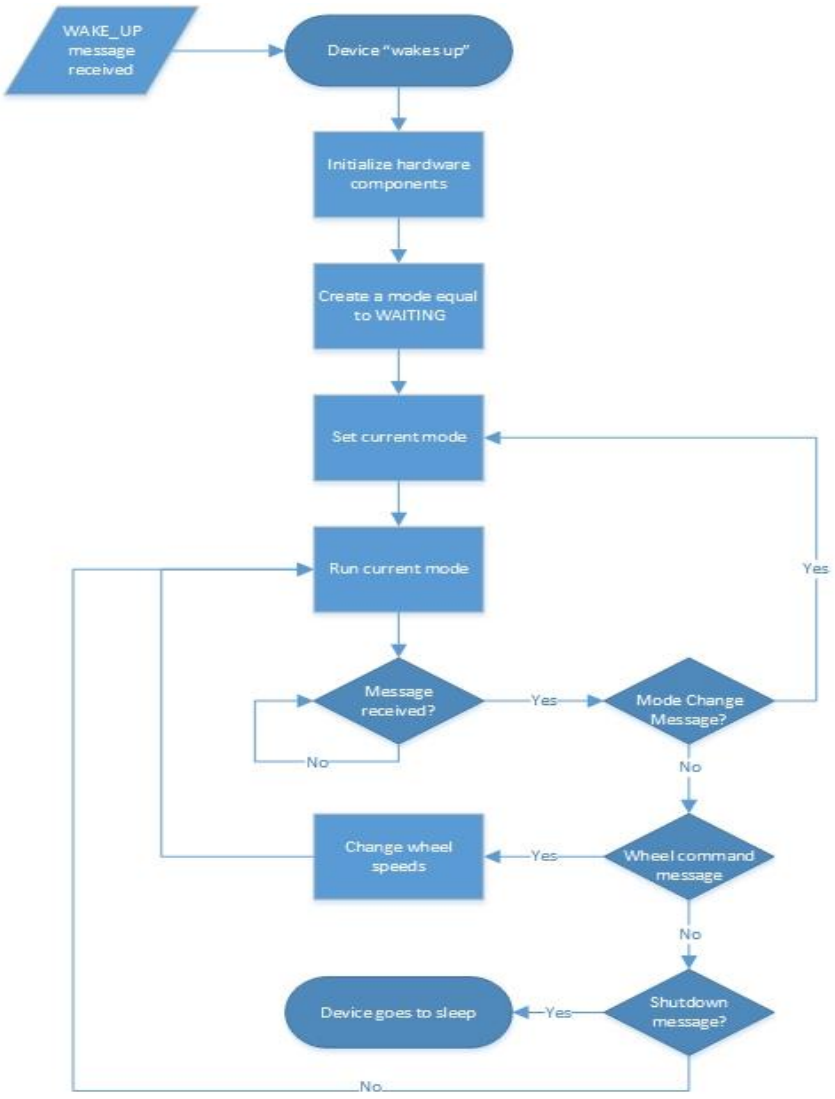

Figure 6.3 Flow diagram for Puppy Pal software

Although the shutdown message is a *Mode* message, and therefore has a corresponding *run* member function (it instructs the system to change into a low power mode and loops over new message arrivals) it is more intuitive to think of it as its own separate messages that simply ends execution. As shown in the figure, there are really four types of messages that can be received: wakeup, mode change, wheel command, and shutdown. Other messages that may arrive are specific to a mode that the system will be running in.

The Android application has a usage flow that is completely controlled by the user. The user has two options when presented with the main screen of the application. The first goes into a “control mode,” where the user can command the Puppy Pal device by moving a circle around the screen. The circle represents a joystick, in that if you move the device forward and slightly to the left, the device will move forward and slightly to the left. The user may also choose to create a path for the Puppy Pal device to remember. In this mode, you are presented with a blank screen representing the play area the device functions in. The user can drag his finger to create a path, and assuming that the path is valid (see Android Application Requirements section of this document) and the user is happy with is path, he can send it to the device for it to remember and run at a later time. Figure 6.2 shows an overview of these processes.

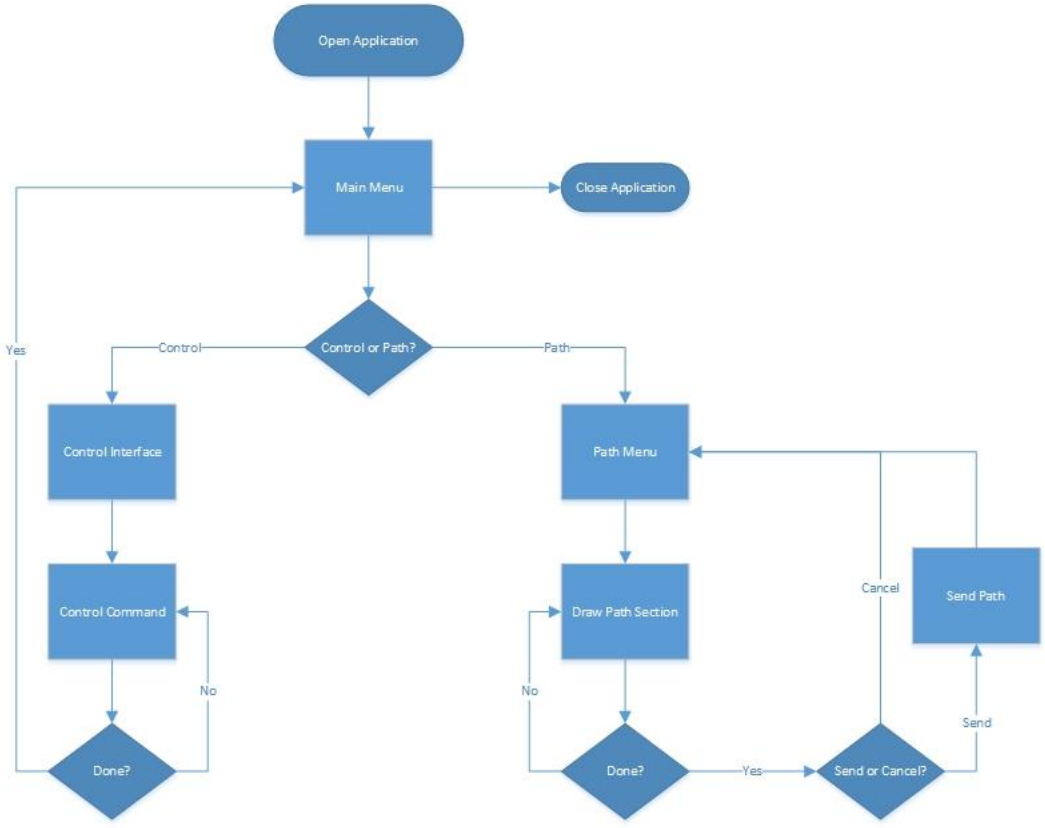

Figure 6.4 Flow diagram for Android software

The collar system has only one function: broadcast a message after a certain threshold of acceleration is detected in the accelerometer. Although the collar is two separate components, it is intuitive to think of it as a single unit. Figure 6.3 shows the data flow. Because the system is so simple, Figure 6.3 is very accurate to the flow of execution in the actual code.

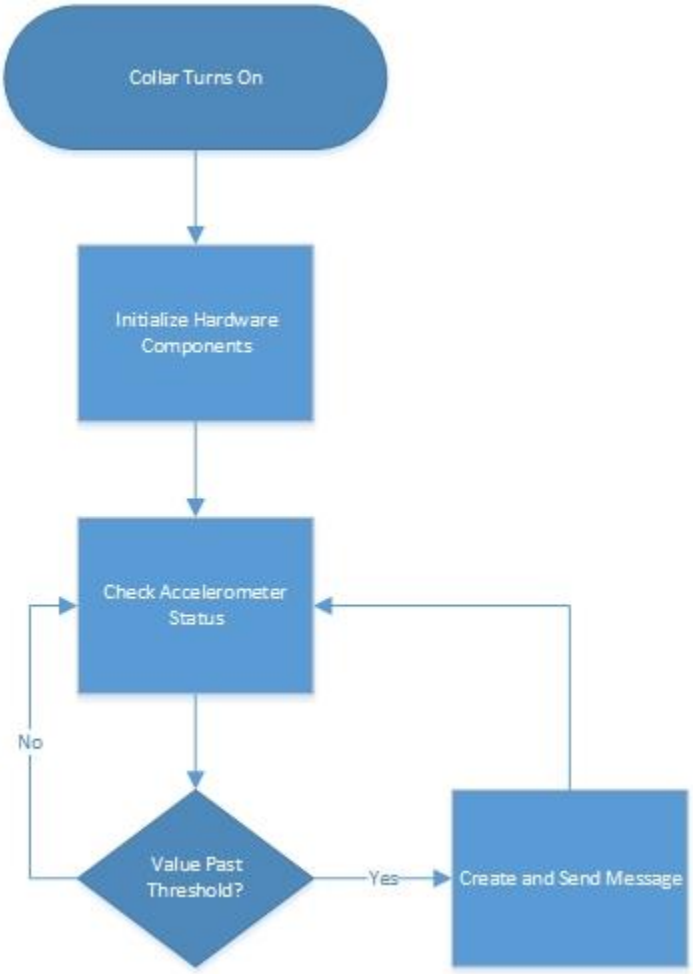

Figure 6.5 Flow diagram of collar software

7 Project Prototype Testing

Puppy Pal is the accumulation of various subsystems working together in order to play with a dog with both human inputs and autonomous control. Each subsystem was tested as it was constructed, completed, and combined with other subsystems. These tests will be as minute as measuring a single accelerometer's output and as massive as observing how a dog reacts to the toy. Testing was not the last stage of the project but a constantly ongoing part of the process.

7.1 Hardware Test Environment

The testing process took place indoors. The electronic components of Puppy Pal were be examined in the Senior Design Lab in UCF's Engineering I building room 456. Multimeters, oscilloscopes, function generators, and power supplies are open to groups for the entire semester. Tests of Puppy Pal's mobility were planned for outdoor and indoor trials to have a variety of surfaces. A video camera was be used to film testing. This film can be examined later. Pictures were taken throughout the process to document progress.

7.2 Software Specific Testing

7.2.1 Puppy Pal Software

There will be three modes that the software for the Puppy Pal device can be build in: *RELEASE*, *DEBUG*, and *UNIT_TEST*. *UNIT_TEST* simply unlocks the self test of the device and sets the main function to perform a set of unit tests that each module of the program has. Tests light a green LED for pass and blink a red LED for a failure, each for three seconds. In addition to blinking LEDs, messages will be sent from the Puppy Pal device to an Android device to display a specific test name and the text "Pass" or "Fail," to make testing information more human readable.

Hardware Interface Test (TestID: 00000)**:** The HardwareInterface class is arguably the most important of all the classes. Eventually everything that the Puppy Pal does uses the hardware of the device. The test for this class shall exercise toggling the output voltage to all GPIOs. An oscilloscope will be used to test the output voltages on all the pins. There are also two PWM units that will be used to control the motors. An oscilloscope will be used to assure that the output pins are oscillating at the correct duty cycle. Faked bytes will be filled into the UART send and receive byte registers, and the data shall be written and read and confirmed that the data is correct.

Message Factory Test (TestID: 00001)**:** Messages that arrive contain the message type as the first four bits. The bytes of a new message shall be sent to the MessageFactory and the message factory shall return a message of the correct type. Messages also need to be registered into the factory before they can be generated. To assure this is working, after each messages and their corresponding generate functions are placed in the factory, the size of the list containing the registered messages should equal to the number of messages that are registered.

Moding Test (TestID: 00010)**:** Being able to change modes allows the system to behave in a certain way. The test for this class will be very involved because each mode has so many different sub-options. First and foremost, the test shall change to every mode registered and verify that the current modes run function is running. For each mode, the ModeMachines *get_current_mode()* member function shall be used to get the currently running mode and check that it is equal to the actual mode that is running. After each mode change, the member function *get_last_mode()* shall be invoked to assure that the last mode is indeed the previously run mode. Each mode's *run()* member function shall be called to assure that each mode is running correctly.

Message Test (TestID: 00011)**:** Each message plays a vital role in the system as a whole. If messages are not functioning correctly, the system essentially does not perform correctly. To test them, two bytes of a fake message of value 0xFFFF shall be created and sent to the current messages *unpack()* member function to assure all data members of the message are equal to some sequence of ones. Then two empty bytes shall be created and the messages *pack()* member function shall be called to assure that the bytes are equal to 0xFF. Then the messages *run()* member function shall be called to assure that the routine runs during program execution.

Movement Test (TestID: 00100)**:** The Puppy Pal device shall be able to move forward, backward, turn left and right while doing so, and do a 360 degree turn while stationary. This test shall first test that it moves forward by moving five feet forward, then backward by moving five feet backward to its original location. The test shall assert that the device can turn left and right by performing a circle of an approximate circumference of fifteen feet first turning right, then left. Next the test shall assert that the device turns in 360 degrees while staying stationary.

7.2.2 Android Software

The Android can be tested on a PC using the Android integrated testing framework. With the addition of a USB Bluetooth module, every aspect of the application can be simulated. Assuming all Android tests pass, the application will be able to open and control the device without error.

Path Draw Test: A major aspect of the Android software is to be able to draw a path for the device to follow. To test this, a user shall stress test the drawing abilities of the application, making sure that no skips or offset paths occur. Two buttons will be available, and the test shall assert that pressing the “cancel” button discards the current path, and that pressing the “accept” button saves the current path and converts it into a message. The path must also be closed by the time it has finished. The test shall assert that unclosed paths are disregarded. If a path is closed, but has too much extra path past the point of closure, the path shall be taken up to the point of closure and no further. The test shall assert that extra path lengths are disregarded in this case.

Message Test: The messaging system on the Android and Puppy Pal devices are one in the same. Therefore, the testing will be the same. All messages shall exercise their *unpack()*, *pack()* and *run()* member functions.

Device Controller Test: To control the device, the user shall be able to drag a circle a distance away from an origin on a plane much like an x-y plot. This test shall assert that the object being moved around the screen moves smoothly and the data feedback is accurate to within 1 unit of the plot. The test shall assert that any value chosen by the user that is between two integer values on the plot is rounded down to the nearest integer.

Automatic Bluetooth Detection Test: While the Puppy Pal device is in its waiting, charging and autonomous modes, it shall be able to connect to an Android device. The Android device upon startup shall automatically connect to the Puppy Pal device, assuming that the device is on, functioning correctly, and in a proper state for Bluetooth commands.

7.2.3 Collar Software

Motion Test: The test shall assert that the collar system is only alerted when there is movement of more than 2g on the accelerometer. The test shall also assert that if values are greater than the movement threshold for 5 seconds, the collar broadcast a Bluetooth message indicating that the dog is ready to play.

Message Test: Only one type of message is sent from the collar to the Puppy Pal device, and the collar never receives messages. This test shall assert that the message being sent from the puppy pal device is of the correct message type. The test shall assert that of 20 messages that are sent, all 19 of those 20 should contain correct data by the time it is received on the Puppy Pal device.

7.2.4 Bluetooth Software

Bluetooth Name Test: The Bluetooth receiver/transmitter on the Puppy Pal device shall be named “PuppyPal,” the bluetooth device on the collar shall be

named “PuppyPalCollar,” and the phone shall broadcast under the name “PuppyPalController.” Each device shall be able to identify the other two devices and connect to them.

Valid Message Test: The bluetooth receiver/transmitter on the Puppy Pal device shall receive two bytes before it assumes a complete message has arrived. The device shall check the received two bytes for their integrity by asserting that the first four bits are a valid message index.

UART Communication Test: The bluetooth receiver/transmitter of the Puppy Pal device shall send received messages to the main processor via UART communications. To test this, the processors shall send fake messages to the Bluetooth receiver, telling it to create a valid message and send it back, with all data fields equal to 0XFFFF. The message shall be acknowledged and checked for correct values. If messages are not correct, and error will be alerted, otherwise, the test is considered a pass.

Bluetooth Message Integrity Test: A baud rate of 9600 will be used to ensure that message are sent quick enough with minimal error is receiving. This test will stress test the sending capabilities. The test shall send 50 Bluetooth messages and assert that 96% of the messages, 48, have arrived correctly.

7.3 Hardware Specific Testing

In this section, examination of the different features and subsystems of Puppy Pal is discussed. These tests measure how closely the project has came to the initial goals. Testing shows if different parts behave as expected. They brought insight to the project, demonstrating the progress made.

7.3.1 Speed Test

Different types of surfaces were going to be used to see how quickly Puppy Pal can accelerate to top speed and to find what that speed is. A straight distance of 30 feet was to be set on the different surfaces. Two different stop watches were planned to keep track of the time from the start to the end of the track. The average time was going to be entered into Table 7.1. An average speed in feet per second was going to be calculated with the data in Table 7.1 for each surface.

To measure the effect of the materials on Puppy Pal without the motors, the device was going to be rolled down a ramp with different materials on it. The ramp would have the same elevation throughout as a control. The different materials would have been draped over the ramp, where applicable. The times of descent would be recorded in Table 7.1 as well, with the distinction of being a ramp rolling test. These trials would have given more insight into the amount of

friction Puppy Pal faces against different surfaces. In addition, the ramp would have also been used to measure how quickly the device can go up. The toy would start 10 feet away from the ramp. It would accelerate and then climb the slope. The same angle would have been used for all materials and the ground used for the initial acceleration would also stay consistent.

A similar exam would have found the angle at which Puppy Pal can no longer climb. The ramp constructed would have a variable angle that can be changed as the tests continue. Starting from 15°, the angle was going to be changed by 15° after five trials of trying to ascend the ramp. One of the testers would stand behind the ramp to catch Puppy Pal if it falls off the ramp. Whether or not the device made it up the ramp and the time it takes to do so was to be recorded in Table 7.2.

7.3.2 Remote Control Test

The remote control tests the parameters that are involved when the Puppy Pal is put into remote control mode. Most tests revolve around the Bluetooth module and Android application. The tests involves Bluetooth range testing, Android response testing, button control testing, tilt control testing, and other testing procedures. Since there will be no speed control the user will have access to, speed tests or mobility tests will not need to be conducted when the system is under remote control mode. The user will not be able to configure mechanical aspects of the system, other than movement.

7.3.2.1 Android/Bluetooth Connectivity Testing

Android/Bluetooth connectivity testing is based on if HC-05 module is reading in the data from the Android device. Testing procedures requires a development board with UART connectivity, in this case the Arduino UNO, a computer to display serial read results and a Bluetooth serial emulator on the Android device to send data, in this case BlueTerm. To test the response of the Android device, the user sends a command, specifically an ASCII character from BlueTerm, if the Android response is correct, the character is displayed to the screen through the UART serial connection via USB between the computer and the Arduino UNO. Multiple characters will be tested to make sure the Android device will be able to send any ASCII character.

7.3.2.2 Bluetooth Range Test

The Bluetooth range tests the range that the user is be able to control the device from. According to the specifications of the HC-05 module, it is stated that it has a line of sight range of 30 feet, which is dependent on the envrionment the module will be in. Range testing is testing the line of sight range and range when there are obstacles corrupting the line of sight. To test the Bluetooth Module, the

module was connected to a development board. For this situation, an Arduino Uno was used to test the module due to the easy to program feature and the simplicity of assigning I/O. A simple program was developed in the Arduino IDE software to basically set a specific pin output high when the MCU reads in a serial input from the UART. Then the character will be printed to the computer screen. To send data to the Bluetooth module from the phone, a Bluetooth emulator application was used, specfifically BlueTerm. The testing procedure is simple, basically the userwill intially stands a specific distance from the module, then they sent a character from the emulator to see if the character is printed to the computer screen. Table 7.1 displays the line of sight Bluetooth range test results. The hypothesis is that the HC-05 module was responsive up to 25 feet and is out of range around 30 feet.

Distance (ft.)	Character Sent	Character Received (Expected Results)	In range? (Expected Results)
1	“1”	“1”	Yes
5	“A”	“A”	Yes
10	“b”	“b”	Yes
15	“4”	“4”	Yes
20	“3”	“3”	Yes
25	“y”	“y”	Yes
30	“l”	N/A	No
35	“L”	N/A	No
40	“9”	N/A	No

Table 7.1 Line of sight Bluetooth range test results

Additional procedures were taken in order to test the range when the module and phone are not in line of sight. For example, when the module and phone are in separate rooms or when they are in the same room but there is an obstacle like a couch disrupting the line of sight. Table 7.2 displays test data from when the module and Android device are not in line of sight.

Situation	Is the module responding? (Expected Results)
Module/Phone separated by small disturbance (cloth)	Yes, Module is receiving data from the phone
Module/Phone separated by medium disturbance (couch)	Yes, Module is receiving data from the phone
Module/Phone separated by large disturbance (wall)	No, data is not being received from the phone

Table 7.2 Obstacle disturbance range test results.

7.3.2.3 Button Control Testing

The Android application used for the Puppy Pal will provide two different ways to control the project. One way is button control, which the user will control the project from the touchscreen functionality from the Android device. The button control interface displays four buttons on the touch screen of the Android device, which correlates to the four directions of movement. Button control testing requires a test board with a UART serial communication functionality, a HC-05 Bluetooth module, and four LEDs that represents the four different directions of movement. A visual block diagram of how to set up the test procedure is shown in Figure 7.1. Each LED represents one movement such as, forward, backward, left, and right. To confirm the buttons are functioning correctly, is dependent on which LED turns on. If the user pushes a specific directional button, then the LED represented by that direction that turns on. Once the user lets go of the button, the LED turns off. For remote control testing, the green LED represents forward motion, the blue LED represents backwards motion, the red LED will represent a right turn, and the yellow LED will be representing for a left turn command.

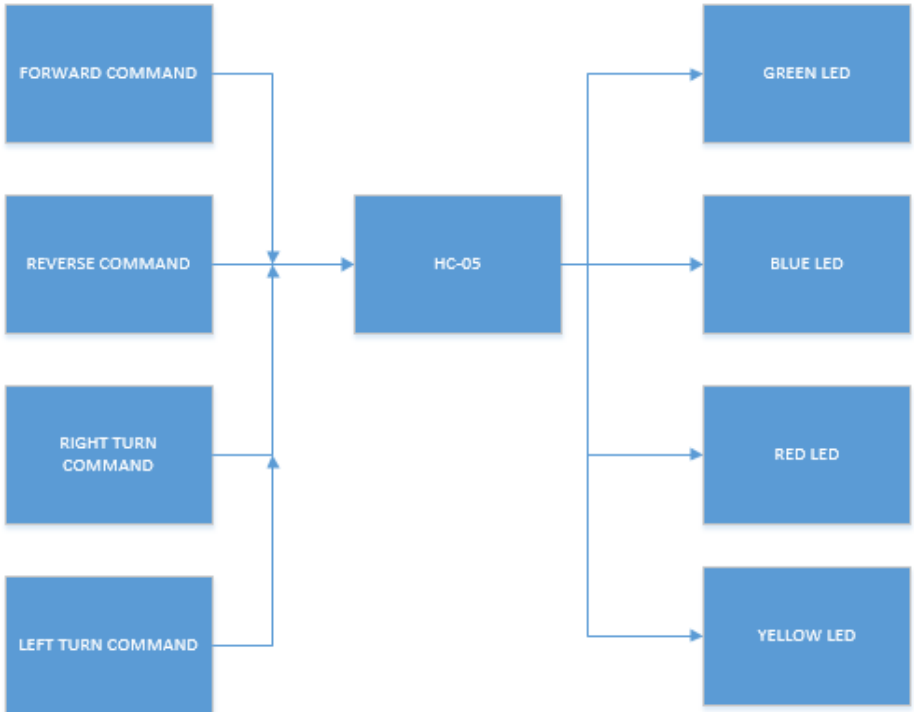

Figure 7.1 Android RC test procedure for button and tilt control.

If all components are working correctly, when the user pushed the forward command, the green LED turned on, for reverse the blue LED turned on, for a right turn the red LED turned on, and for a left turn the yellow LED turned on.

7.3.2.4 Tilt Control Testing

Tilt control testing was conducted in a similar fashion as in the button control test, the major difference is that the accelerometer function of the Android device was tested to send out movement commands. Direction of tilting represents the command that is sent, for example if the system is functioning correctly and the user tilts the Android device forward, it correlates to a forward movement command. The same test procedure used in the button control testing can be used.

If the tilt control is functioning ideally, when the user tilts the Android device forward, the green LED turns on. For a reverse tilting motion, the blue LED turns on. For a tilting motion from 30 to 90 degrees to the right, turns the red LED on, and for a left tilting motion the yellow LED turns on.

7.3.2.5 Timing Response Test

It is important to test the timing in remote control mode between when the command for the motion is sent and when the ball starts moving. Since timing was too difficult to actually measure, the testing is purely observational. Too much of a delay is not acceptable, because if there is a significant delay between command and action, it is harder to control the ball. Under the most optimized situation, when the user sends a command using button control a delay of 500 to 1000 milliseconds is expected. To confirm if timing response is adequate, when the user sends a command it appears to the human eye that the device starts moving once the button is pushed. In addition, it is expected that when the ball is being control from tilt control there will be a little more delay in comparison to the button control.

7.3.3 Autonomous Movement Test

After assembly has been completed, the autonomous mode will be tested. The test will be video recorded. After setting the play area and placing Puppy Pal in the base charging station, one of the testers will enter the play area wearing the collar. Puppy Pal should sound its buzzer. The tester will calmly walk the perimeter of the play area, which will be marked with cones. After a lap, the tester will skip around the perimeter. Puppy Pal should start to chase the tester. Then the tester will jog across the play area and be followed. The tester will sit down. Puppy Pal will buzz at and move around the tester. Eventually, Puppy Pal will stop and return to the base charging station. The video will be used to determine Puppy Pal’s reaction time to stimuli.

7.3.4 Durability Tests

Puppy Pal was expected to withstand the abuse of a highly destructive dog. Its physical limits had to be found before the device could be considered ready to interact with an animal. The features that were to be determined were the heights from which Puppy Pal could be dropped, the amount of time it could be shaken vigorously, and how easily the plastic enclosure could be opened.

Dogs were expected to pick up and toss Puppy Pal around. This action would have been imitated. A tape measure was to be placed along the wall. Starting from one foot, the toy was going to be dropped. Before the internal structure of Puppy Pal is inserted, the empty ball was to be dropped, not thrown down. If the toy didn't burst open on impact, the trial was considered a success. The ball would have been inspected closely to determine if any damage had occurred. The height would increase by one foot until seven feet was reached. Seven feet was the limit because a tall dog is unlikely to throw a ball higher than six feet; the extra foot accounted for this uncertainty. Three sets of trials were going to be done for each elevation before moving on to the next height. The results would have been recorded in Table 7.5. The test were going to first be done with a carpeted floor, then repeated with tile.

The drop test was going to be repeated when the project was completely built. If there were a height at which most of the trials were a failure in the first drop test, this would have become the new maximum height. After hitting the floor, the cell phone connected to Puppy Pal would tell the toy to move. If it behaved normally, the trial was a success. Table 7.3 would be used again for this experiment. Each trial would be video recorded for future review.

To model the shaking of the toy, testers would have picked up Puppy Pal and shaken it for ten second intervals. After a minute of shaking, the toy would be placed on the ground and the remote control tested. Puppy Pal's functioning normally would have been recorded as a success in Table 7.6. This would be repeated ten times or until a failure occurs.

An alternative to shaking the ball by hand was to use a machine. A machine designed to shake objects would be more likely to have a controlled amount of movement, acting as a control for the experiment. The testers would strap Puppy Pal into a body vibration machine. Once secure, the frequency and speed would be set. For this test, the speed would be constant. The ball was going to vibrate at each frequency for five minutes. A success was defined as Puppy Pal behaving normally when given instructions once placed onto the ground. Table 7.5 below would have been used to hold the results.

7.3.5 Motion Detection Test

The motion detection test will determine the functionality of the motion detection system. There will be two separate tests, one determining the functionality of the proximity sensors on the Base Charging Station, and one determining the functionality of the motion detector on the Collar. In addition to the two individual tests, one final test will be conducted once the entire system has been built.

The method for testing the collar will include tests simulating the motion of a dog adjusting during sleep, a dog waking up and moving, and a dog returning to sleep. The test of the dog adjusting during sleep should trigger an interrupt from the accelerometer waking the Bluetooth SoC to process the data and result in the device returning to sleep without transmitting. The test of the dog waking up and moving should result in an interrupt from the accelerometer waking the Bluetooth SoC to process the data and result in the device transmitting the motion detected signal to the ball for further action. The test of the dog going to sleep should result in the collar determining that motion is no longer occurring over the specified time interval and transmitting the play ended signal to the ball and the collar returning to sleep.

7.3.6 Wireless Charging Test

The first test for wireless charging will be a very simple test, only requiring the wireless transmitter module, the wireless receiver module, and a LED with a series resistor to dissipate the extra power. For the first test, the transmitter coil and the receiver coil will be placed on opposite sides of a piece of cardboard and the test will be considered a success if the LED lights up. The next wireless charging test will require two multimeters with two inputs each. One input of each will be a current probe wired in series with the power flow on the supply voltage side and one will be a voltage probe wired in parallel between the power supply and a ground connection. Efficiency will be tested over a number of ranges between the transmitting and receiving coils and various materials, most importantly the possible materials that the ball may be constructed from, will be placed between the coils to determine the effects on efficiency. For the final test, once the entire device has been assembles, the modules will be integrated into the final device and will require that some additions be made to the design to facilitate the testing process. The voltage probe will be easy to connect, as the only requirement is a pad or pin connected to the positive supply voltage and a pin connected to ground. The current probe will require a place on the circuit board where the flow of current can be broken and re-routed through the current probe. This will likely be a pair of pins connected in series with the power supply’s current flow and located on the surface of the PCB, that are normally shorted, with a removable jumper that allows the insertion of a current probe directly in series with the power supply current. Multiple pairs of pins may be

wired in order to determine the efficiency of individual components, with the most important locations being the very beginning of the current flow at the output of the outlet, used to measure total efficiency of the power transfer, and one located directly at the input of the power transmitter, to measure only the efficiency of the wireless power transfer. The measured supply current and supply voltage will be multiplied together to calculate the total power supplied and the total power flowing into the system. This process will be repeated on the supply side, with one pair of pins located as directly at the receiver's regulated power output. As many test points as possible on the PCB will allow more efficient analysis if a problem is found and may allow problematic systems or components to be directly located. There is no definitive threshold for a successful test, but rather a continuous spectrum with ever higher efficiency with minimal redesign being the primary goal of this series of tests.

7.3.7 Battery Life Test

The first step for determining battery lifetime is to determine the power consumption of each subsystem. Frequency and duration of operation can be approximated to determine an overall average power consumption value, which can be used in conjunction with the required battery life time to provide a minimum energy capacity estimate for the battery, which much greater certainty than the previous calculation made in section 4.8.3. These tests can be performed using bench equipment, such as multimeters and power supplies to allow for the best selection of a final battery. Once the battery is decided upon and purchased, battery life tests will occur periodically as development progresses, with the first test being simply verification of lifetime with only a simple motor control system and motors connected, and the last test being performed once all systems have been integrated and all designs adjusted to work properly. The periodic tests will give insight into changes that may have occurred since the initial bench testing, or problems that may arise and provide possible solutions that would otherwise require more intensive testing at the end to resolve. As stated previously, the expected battery life time is to be 10 hours assuming normal usage. Normal usage is described and used in the design calculations in section 4.8.3, but will be much more accurately determined when the dog interaction test is performed. A successful test will be a device with consistent battery lifetimes of greater than 10 hours, however, the success measure for this test is a continuous spectrum with greater values being better. Maximizing battery lifetime without increasing final cost is the true goal of this test.

7.3.8 Dog Interaction Test

The dog interaction test will serve multiple purposes, including determining what normal usages for this toy may include, and determining how well the device is performing its function. This will likely be the very last test performed and will

serve to determine what adjustments need to be made in terms of sounds, motions, and exterior appearance. This information can be used to make adjustments to the autonomous motion control system, to correct for any behavior that the dog may be intimidated by or behavior that may cause the dog to lose interest. The only possible required equipment for this test is a video and audio recording device, to determine how the dog interacts with the device without people around. In addition to the tests that will be performed in autonomous mode, tests should also be done with the user input mode to determine how well the autonomous mode compares to the human control mode, and what noticeable difference is seen between the two.

7.3.9 State of Charge Test

In order to properly monitor Puppy Pal's state of charge, its battery's capabilities needed to be studied. The battery pack would power a circuit designed to specifically drain the battery. The current sensor would measure the current flowing through the battery pack. The sensor would send its data to a microcontroller connected to a computer. The circuit would run until the battery dies. The current behavior was to be stored for analysis in MATLab. The group's hypothesis was that when the current changed suddenly, the battery entered a low-power state. The opposite was assumed when the battery was close to being fully charged. The battery's measured current voltage information was going to be graphed on a single plot to look for a pattern. In addition, the integration of the current signal would also be saved. This data would show whether or not measuring and integrating current was an effective method for measuring Puppy Pal's state of charge.

Figure 7.3 is a block diagram representing the power drain portion of the State of Charge Test. The battery pack is the power supply. Current is flowing from it into the current sensor and throughout the draining circuit. Figure 7.4 is a block diagram representing the charging portion of the State of Charge Test. The main difference in this circuit is the addition of an AC source and transformer. The AC source's signal goes through the transformer and filter, becoming a DC signal. The DC signal is sent to the battery pack wirelessly to charge it. The current sensor and computer have the same roles. The draining circuit is now the load. This experiment would provide enough information to accurately predict the charging and discharging of Puppy Pal and alert the system when it was time to return to the base charging station. If this did not turn out to be the case, then the State of Charge Test would be redesigned or repeated.

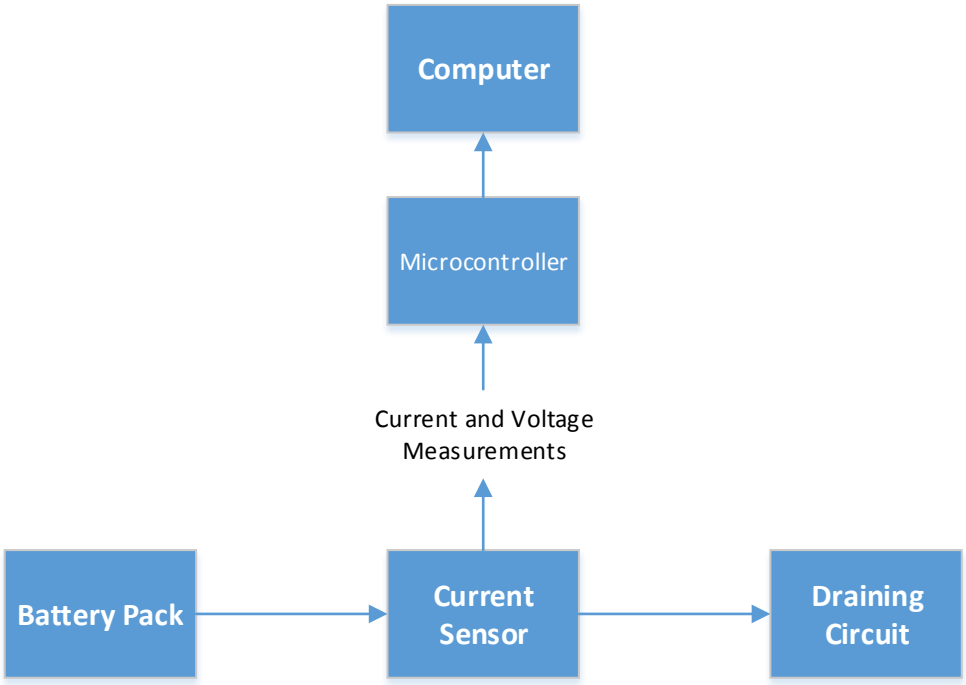

Figure 7.3 Block diagram depicting the structure and flow of current and data for the discharging stage of the State of Charge Test.

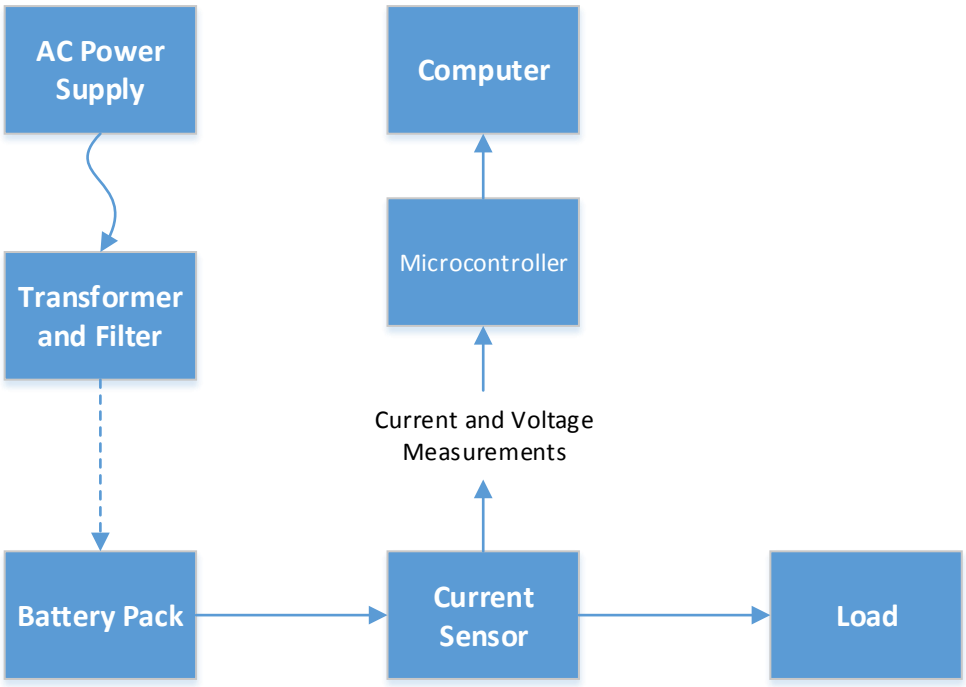

Figure 7.4 Block diagram depicting the structure and flow of current and data for the charging portion of the State of Charge Test.

8 Administrative Content

8.1 Budget

Cost efficiency is the key and the budget was planned to be kept significantly small, as not one component was over $100.00 except for the ball PCB which came out to 316.00. The majority of budget comes from the rechargeable battery,shipping costs and PCB fabrication process. Table 8.1 displays a budget list for the Puppy Pal.

Component	Quantity	Price
Ball Enclosure	1	10.99
Arduino Mega 2560	1	15.00
Bluetooth Module(s)	5	20.00
DC Motors	2	10.00
Android Device	1	Owned
PCB Ball	1	316.00
PCB Dog Collar	1	50.00
Accelerometer	1	5.00
Gear Box	2	12.00
Misc. Mechanical Parts	1	30.00
Misc. Electrical Parts	1	20.00
12 V Battery	1	40.00
Dog Collar Battery	1	20.00
Total	**19**	**548.99**

Table 8.1 Budget Table

8.2 Finances

Boeing is financing up to $197.00 of the project's budget and the rest of the finances werepaid within the group. The PCB fabrication of the ball was purchased with the Boeing funding. The rest of the components such as ICs, miscellaneous electrical components, and non-expensive wireless modules were funded by the group. Strict records of purchases will be kept throughout the process. All group members should receive a copy of the order confirmation via email. Boeing funded 197.00 worth the project and 351.00 were spent out of pocket.

8.3 Milestones

The construction and testing phases of the project was 10 weeks long, from May 12 to July 24. Table 8.2 provides a week-by-week breakdown of the entire process. It includes the activities to be completed and their respective deadlines. As the project continued, the milestones were updated with new tasks and deadlines for specific group members.

	Tasks and Deadlines
May 12 – 18	• Start receiving previously ordered parts. • Begin assembly of mechanical system. • Discuss any new ideas for the project; make changes accordingly.
May 19 – 25	• Begin coding for the microcontroller. • As parts arrive, test them. If they do not work as expected, contact the companies for replacements.
May 26 – June 1	• Begin coding for the app. • Test the designed circuits with breadboards and microcontroller launch pad.
June 2 – 8	• Deadline: If the mechanical system does not work, fix it or find a new system.
June 9 – 15	• Deadline: Complete microcontroller coding.
June 16 – 22	• Deadline: Order the PCB. • Deadline: Complete app coding.
June 23 – 29	• Test the Bluetooth pairing between the different subsystems.
June 30 – July 6	• Deadline: Solder parts onto PCB. • Deadline: Assemble all subsystems.
July 7 – 13	• Deadline: Interface of all subsystems. • Go through performance tests.
July 14 – 24	• Deadline: Artistic detailing.

Table 8.1 Milestones

8.4 Decision Making Process

Throughout the prototype construction and testing stages, previous design choices were revised. Some parts did not work; others were too difficult to assemble; deadlines arrived too quickly for some tasks to be completed. When problems arose, the group member who found it made the rest of the group aware of the problem. He would work alone on the issue for two days. If the problem had not been resolved, at least one other group member started to work on it as well. After three days, the entire team considered the problem for two days. If no solution had been found, the group took a day off from thinking about this component and concentrated on other parts of the project. Then the team discussed the issue. If the problem was delaying a vital subsystem's assembly, the group decided to continue trying to fix it, to wait two more days before resuming work on the subsystem, or to abandon that part of the project entirely. The first two choices required a majority vote. If no agreement could be made, the project leader would flip a coin. If heads, the group continues to find a solution. If tails, the group shelved the issue.

The third option demanded a unanimous decision and a meeting with Dr. Richie. The elimination of a part of the project would change the scope of the project, something that had to be discussed with Dr. Richie, and could have potentially left a group member with nothing to present at the end of the semester. The unanimous decision gave the decision more weight and made it difficult to cut out parts of the project some may have considered important. The meeting with Dr. Richie would provide the insight of an objective party that could inform the group's decision. This procedure made it so that no one felt as though his part of the project was unimportant or that his opinion didn't matter to the rest of the group.

8.5 Group Responsibilities

Each member of the group had a primary responsibility and additional responsibilities that were worked on with the other members of the group. The table 8.3 below displays the group responsibilities.

	Marshall Smith	**Cameron Riesen**	**Afzal Shafi**	**Anson Contreras**
Mechanical Design	x		x	●
Motor Control		x		●
Android Application		●	x	
Communication		x	●	
Location Detection	x	●		
Motion/Proximity Sensing	●	x		X
PCB	x		●	
Power System	●			X
Embedded Software		●		
● - Key Responsibility	x – Contribution			

Table 8.2 Group responsibilities

Appendices
Appendix A - Copyright Permissions

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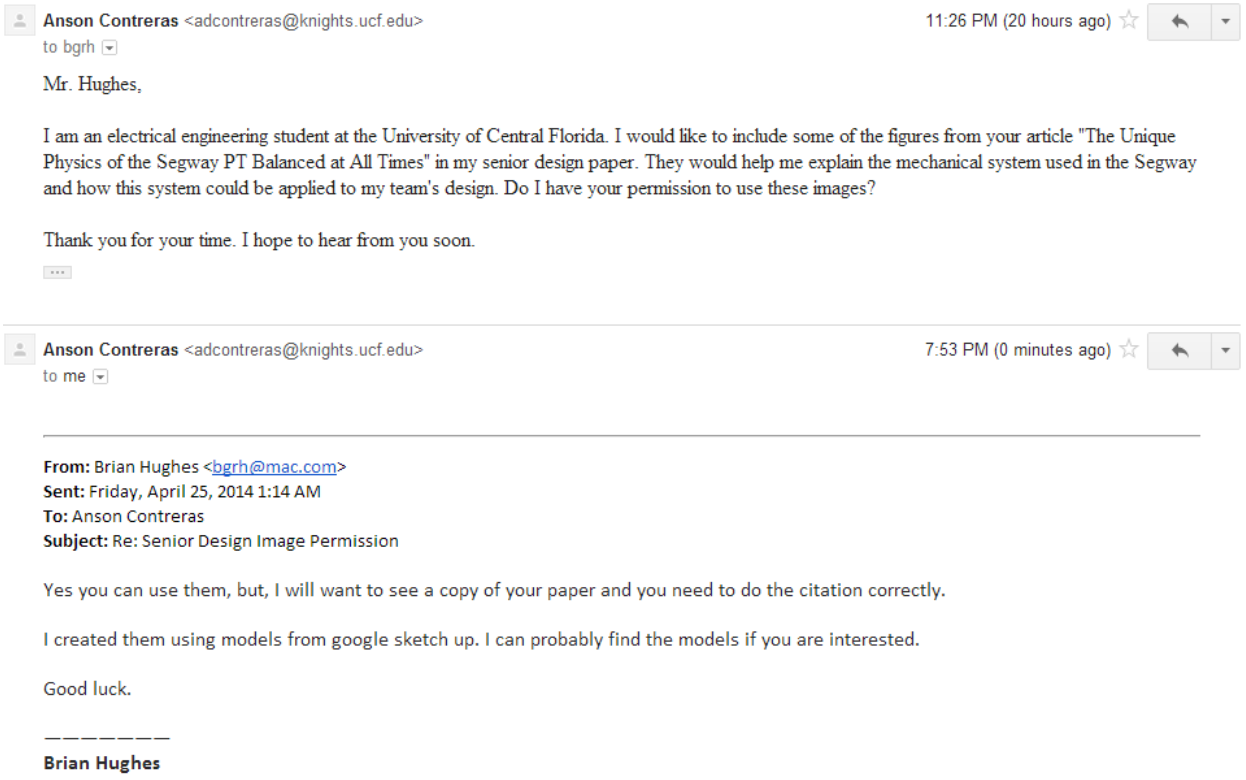


Anson Contreras <adcontreras@knights.ucf.edu> 11:26 PM (20 hours ago)
to bgrh

Mr. Hughes,

I am an electrical engineering student at the University of Central Florida. I would like to include some of the figures from your article "The Unique Physics of the Segway PT Balanced at All Times" in my senior design paper. They would help me explain the mechanical system used in the Segway and how this system could be applied to my team's design. Do I have your permission to use these images?

Thank you for your time. I hope to hear from you soon.

Anson Contreras <adcontreras@knights.ucf.edu> 7:53 PM (0 minutes ago)
to me

From: Brian Hughes <bgrh@mac.com>
Sent: Friday, April 25, 2014 1:14 AM
To: Anson Contreras
Subject: Re: Senior Design Image Permission

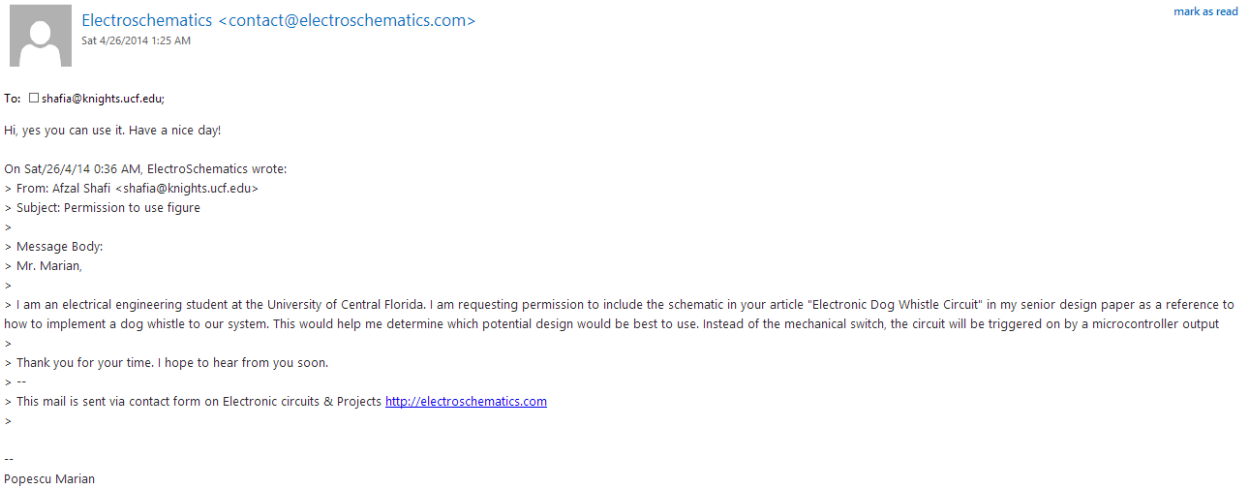
Yes you can use them, but, I will want to see a copy of your paper and you need to do the citation correctly.

I created them using models from google sketch up. I can probably find the models if you are interested.

Good luck.

———————
Brian Hughes

Permission to use Figure 3.3.4.1a



Electroschematics <contact@electroschematics.com>
Sat 4/26/2014 1:25 AM

mark as read

To: ☐ shafia@knights.ucf.edu;

Hi, yes you can use it. Have a nice day!

On Sat/26/4/14 0:36 AM, ElectroSchematics wrote:
> From: Afzal Shafi <shafia@knights.ucf.edu>
> Subject: Permission to use figure
>
> Message Body:
> Mr. Marian,
>
> I am an electrical engineering student at the University of Central Florida. I am requesting permission to include the schematic in your article "Electronic Dog Whistle Circuit" in my senior design paper as a reference to how to implement a dog whistle to our system. This would help me determine which potential design would be best to use. Instead of the mechanical switch, the circuit will be triggered on by a microcontroller output
>
> Thank you for your time. I hope to hear from you soon.
> --
> This mail is sent via contact form on Electronic circuits & Projects http://electroschematics.com
>

--
Popescu Marian

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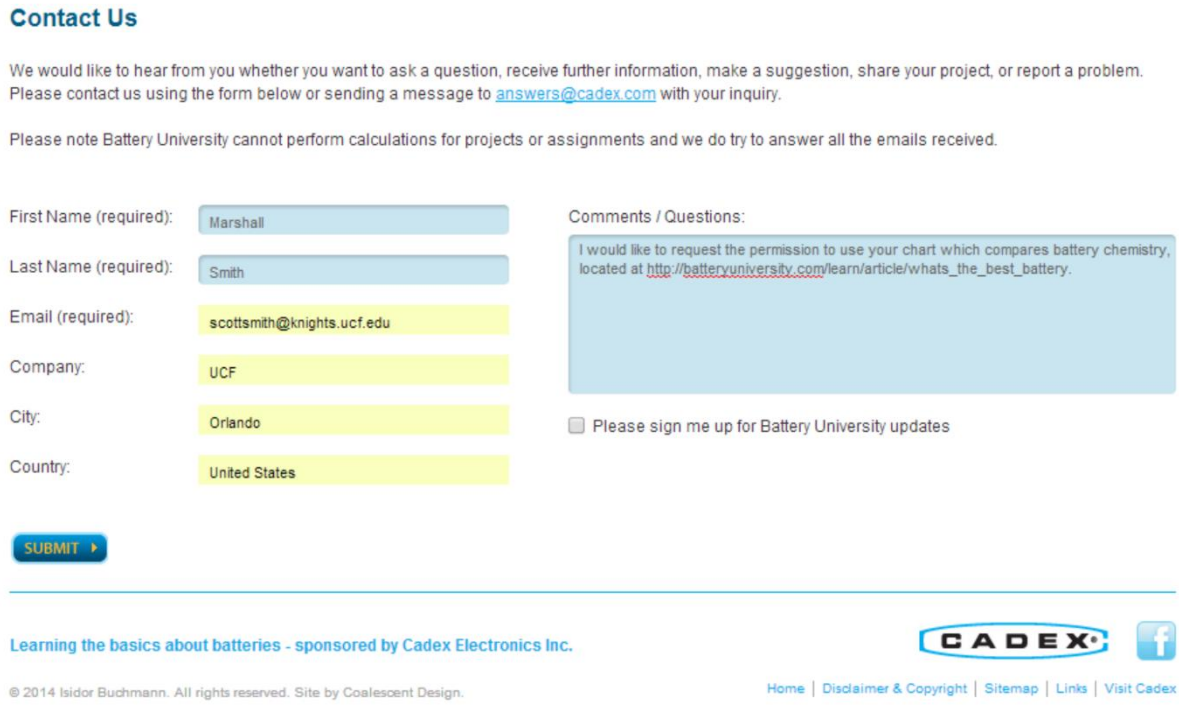

Contact Us

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Please note Battery University cannot perform calculations for projects or assignments and we do try to answer all the emails received.

First Name (required): Marshall
Last Name (required): Smith
Email (required): scottsmith@knights.ucf.edu
Company: UCF
City: Orlando
Country: United States

Comments / Questions:
I would like to request the permission to use your chart which compares battery chemistry, located at http://batteryuniversity.com/learn/article/whats_the_best_battery.

☐ Please sign me up for Battery University updates

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