Puppy Pal

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***Abstract* — This paper details the goals, design decisions, and real world considerations of an autonomous ball robot functioning as a dog toy. The primary goal is to eliminate a dog's destructive tendencies by providing a safer and more desirable exercise. This project aims to create a robot capable of safely and effectively entertaining a dog while the owner is away.**

***Index Terms* — Animal behavior, Bluetooth, computer vision, consumer products, inductive power transmission, mechanical systems, mobile robots.**

I. INTRODUCTION

This project was born from the need for a consumer product capable of keeping a dog distracted during the day to eliminate destructive behavior caused by boredom. Puppy Pal accomplishes this goal by providing entertainment to 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 simply 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 this device. 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, in addition to an audio subsystem, which will generate intermittent animal sounds. The device should not wander aimlessly into potentially unsafe areas, so a user definable play area will be created using a base station and a 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 determine 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 signaling 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 to those already having an Android phone, capable of Bluetooth communication. In the future support could be expanded to apple products and even laptops, but for now only Android will be supported. 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.

II. BLUETOOTH COMMUNICATIONS

There will be three separate wireless communication systems that will need to be implemented into the entire system. For example, there will need to have a method of wirelessly communicating between the ball and the Android device, the ball and the charging station, and the ball and the collar that the dog will be wearing. Ideally, the ball and the charging station will not exceed a significant difference in distance, however 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. The accompanying figure displays the Puppy Pal communications block diagram.

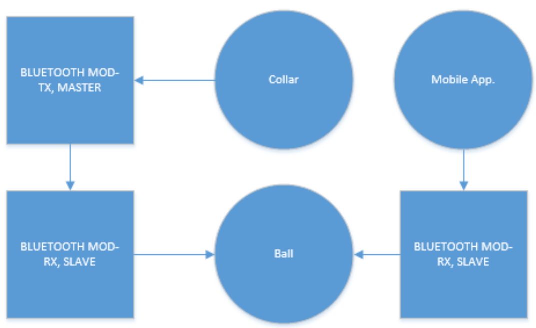

Fig. 1. Block diagram displaying the flow of data via Bluetooth between Puppy Pal's components and the user.

The Bluetooth module that will be used to interface the Android device and Dog Collar 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. The HC-05 can be configured to be either a slave or master device, in terms of interfacing to the Puppy Pal, the module will be 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 will be 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. Another application is that the Bluetooth module will be used to send and receive commands from the Dog Collar. The transmitting module will be located on the collar as the receiving module will be located on the ball. The accompanying displays key specifications for the HC-05 Bluetooth Module.

TABLE I
BLUETOOTH MODULE FEATURES

Operating Voltage	3.3 V
Class	2, 2.5 mW
ISM band	2.4 Ghz
Physical Dimensions	12 x 13 x 22 mm
Baud Rate (used)	9600 bps
Auto Detection	Auto-bond, and Auto-Pair
Role(s)	Master, Slave

As looking at the specification table, one can observe a deficiency in range. As stated for most class 2 Bluetooth devices, the range is approximately around 30 feet. However this module has been tested with a Bluetooth emulator and has overcome the 30 feet range.

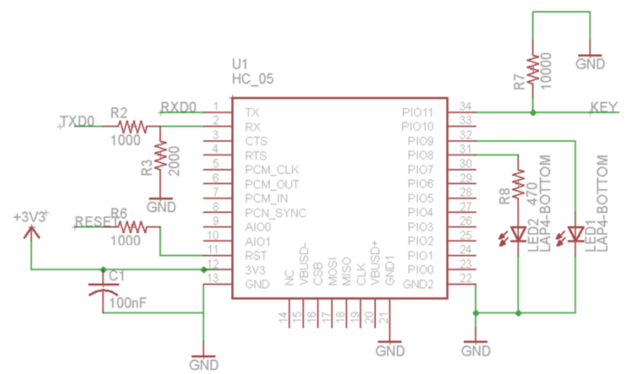

Fig. 2. Schematic diagram of the Bluetooth module and its corresponding connections.

Configuring the module was dependent on how the two devices would be paired. For instance, the module to be connected to the Android device will treated as any other Bluetooth device. The mobile application will search for the specific Bluetooth device, which is in this case the slave device located on the ball, then it will pair the two devices using the MAC address of the module. The mobile application will not be able to transfer any commands unless the two devices are bonded together. This provides reasoning on why multiple modules are needed, the collar and ball will always need a constant bond, similarly the phone and ball as well. Since Bluetooth devices are one-to-one devices, a master device simultaneously connecting to multiple modules at once cannot be obtained. The only primary difference is that when the ball is trying to establish a connection with the collar some manual configuration will need to be done using AT commands.

III. DOG COLLAR

The Dog Collar circuit will be used to detect the motion from the dog. It will be a separate system from the ball, and will be attached to the dog. The motion sensing algorithm will detect a certain threshold measurement of movement and then it will send a command to the ball via Bluetooth. Ideally the algorithm will be dependent on time, the system should not send commands just because motion sensing is triggered, and it will send a command when a constant threshold measurement has been reached with respect to time. The dog collar will be made up of three main components: the first component is the Bluetooth module, as mention before will use a HC-05 module, the second component is the accelerometer used for motion sensing, and a microcontroller for processing. The figure below displays the hardware block diagram for the Dog Collar.

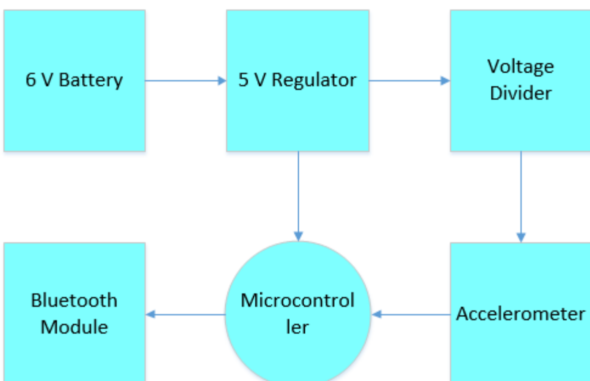

Fig. 3. Dog Collar Block Diagram

The microcontroller does all the processing from the values from the accelerometer. Due to the method of how the collar will be on the dog, only X and Y acceleration readings will be used. The threshold will only be used if X or Y are greater than 0.4 over five to ten seconds. Also, the Z reading must be greater than around 0.8 g, because when the Z coordinates have reached around zero, the MCU is assuming the dog is laying on their back (either X or Y acclerometer will be around 1 g. The microconteroller that will be used is the Atmega328P from Atmel. The table below provedes some of the basic specifications.

TABLE II
ATMEGA32P SPECIFICATIONS

Vcc	5 V
Vin	7-12 V
Clock Speed	16 Mhz
Flash	32 Kb
PWM	6
Serial Ports	2

The accelormeter used is the AXDL-345, which a low power triple axis, accelometer. The device will take reading for all three axis parameters. Also the range can be switched between plus-minus 2g, 4g, 8g, and 16g. The accelermoter uses the SPI communcations protocol from the Atmega328P. The table shown below gives some of the key characteristics of the AXDL-345.

TABLE III
ADXL-345 SPECIFICATIONS

Operating Voltage	3.3 V
Modes	2g, 4g, 8g, 16g
Current	40uA measurement, 0.1 non-measurement
Size	3 x 5 x 1 mm

Some additional parts that will be a part of the circuit is a linear voltage regulator that will regulate the 7 volt input voltage to supply to the MCU. The voltage from the regulator output will be sent through a voltage divider to supply the ADXL-345 power. A schematic of the Dog Collar Circuit is shown below.

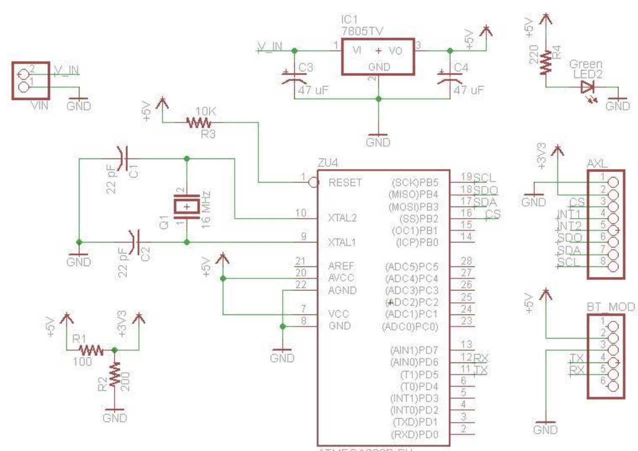

Fig. 4. Schematic of Dog Collar

As observed from the schematic above, it can be seen that the circuit does not require many components and it is designed to be as small as possible. The resistors of the voltage needed the R1 and R2 resistors to have a ratio of 0.5 for the output to achieved 3.3 volts from a 5 volt input.

In addition the MCU clock frequency is at 16 MHz as mentioned before. The battery that will be used to power the circuit will be two 2032 coin cell batteries that will give an output voltage of around 6 volts.

A. Dog Collar Software

The software for the dog collar is fairly based around the behavior of the accelerometer input, the accelerometer is constantly updating the SPI ports with measurements with respect to X, Y, and Z. In order the MCU to be triggered to send a command. For it to trigger, an accelerometer value of the X or Y axis must hit an average value of 0.5 g or higher for a period of 5 to 10 seconds. Once this condition has been met, it will send a command to put the Puppy Pal out of sleep mode.

IV. MESSAGING

Messaging provides a common means of commuication between the different sub-systems of the Puppy Pal . Messages are sent internally and externally (via Bluetooth) and perform tasks of changing the system's mode, change wheel speeds and directions, and waking up and putting the system into a low power mode. Messages are of a generic length depending on the message type, but all messages of the same type use the same format. The only similarity between all messages is that the first byte contains four bits the message type and four bits for the message length, implying that there is a maximum number of sixteen different types of messages that can be created, and each message can be a maximum of sixteen bytes long. Messages are, in their purest form, XML documents describing the length of the message, the message ID, and the name of the different variables inside the message that contain all the information anyone using that message will need. For modules to get messages sent to them, they must inherit from the MessageSubscriber class, and then subscribe themselves to the particular message ID with the MessageRouter object.

V. MICROCONTROLLER

The Atmega2560 is a microcontroller from of the AVR series of 8-bit processors. It has an internal master clock frequency of 16Mhz and 8KB of SRAM. It has 256KB of flash memory, 8KB of which is used for the bootloader. It also has 39 digital output pins and 15 PWM output pins.

A. Pin Mapping

The pin mappings allow the microcontroller to control motors, take advantage of Bluetooth communication and light LEDs for some simple feedback. The table below shows the pins that are used for all of these elements.

TABLE IV
PIN ASSIGNMENTS FOR MICROCONTROLLER

Pin	Controlling element
30	Motor 1 state 1
31	Motor 1 state 2
32	Motor 2 state 1
33	Motor 2 state 2
2	Motor 1 PWM
3	Motor 2 PWM
1	Bluetooth 1 Tx
0	Bluetooth 1 Rx
18	Bluetooth 2 Tx
19	Bluetooth 2 Rx
22	Green LED
23	Red LED

VI. SOFTWARE OVERVIEW

The Puppy Pal software was written in C++ and was compiled and downloaded to the microcontroller using GNU Make/avr-g++ and avr-dude. Because of the limited amount of RAM that most AVR microcontrollers have, the C++ Standard Template Library (STL) and dynamic memory allocation (DMA, and in the sense of creating C++ objects), were not supported. The three major subsystems of the software are message handling, mode changing, and hardware interfacing. Modes allow the system to behave in a certain way. If you think of an embedded system as a never ending loop, modes are that loop, this construct allows the loop to change in a concise and easy to manage way. Some of modes include controlled, where the user is controlling the device, autonomous where the device is running on its own, and sleep where the device is in its lowest power state and waiting for input from its surroundings. Changing modes occurs when a mode change message is created and is handled by a special class called the ModeMachine. Another special class, the HardwareInterface, provides a common access point for all modules of the software to control aspects of the hardware. With these three classes, the system as a whole can function with the aid of other helper classes.

VII. PCB

A. Main Board PCB

The main PCB is located within the ball, and contains the main microcontroller and the battery charger. The board has all connections between systems brought out to headers and wired, to allow for versatility and easier testing in the design phase. This board will also connect to the wireless charging system, and communications system.

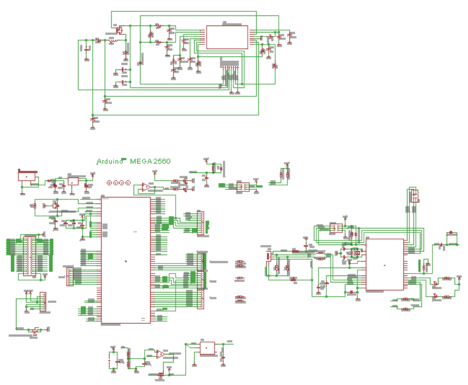

Fig. 5. Schematic diagram for the main PCB. The different functions are separate.

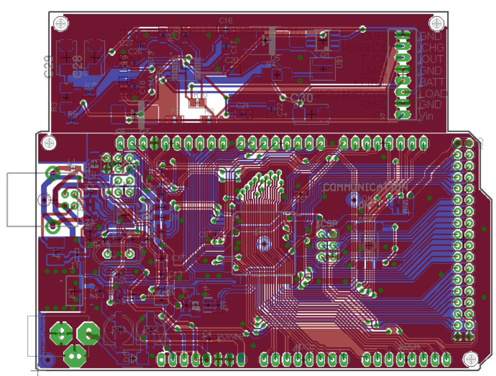

Fig. 6. Board layout for the main PCB

B. Dog Collar PCB

The PCB for the Dog Collar is to be a small as possible to fit inside a non-bulky enclosure that will fit comfortable for the animal. The size of the PCB is around 1.5 by 1.7 inches. The components are a mixture of through hole and SMD components. Most of the SMD components such as resistors and ceramic capacitors used the size of 0603. Through hole components were used for the Atmega328P dip socket and headers for customizable configurations. The figure below shows the PCB for the dog collar.

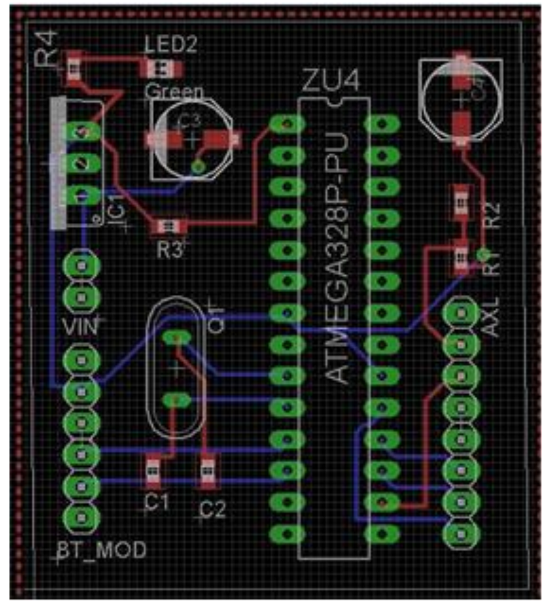

Fig. 7. Dog Collar PCB.

VIII. Mechanical System

Puppy Pal was constructed and housed inside of a plastic ball. The ball is clear, with a diameter of 6.25 inches. A robot of this size and shape required the design of a mechanical system that can drive the motion of a ball from the inside, have precise control, and survive the rigorous play a dog toy can suffer. These challenges were met with a motor driver and control system that can provide motion, and an internal structure that absorbs the force a dog can apply when playing.

A. Dual Wheel System

Unlike traditional robots, a ball robot has linear motion using rotational motion. To drive the robot, the center of gravity is shifted from near the bottom of the ball to a point higher up. The motors rotate the wheels inside of the ball. The wheels, along with the attached internal structure, climb the wall of the enclosure. Most of the balls weight will be moved accordingly. The ball reacts to this change in the center of mass by rolling. At lower speeds, this is most evident. When Puppy Pal is working at higher speeds, however, the climbing motion is not noticeable. The internal structure appears to be resting at the bottom of the ball as it goes along its way. The placement of the majority of the weight of the ball below the center of the ball makes this placement possible. The two wheels will also be used to change directions and give the user control over Puppy Pal.

B. Bumper System

One of the obstacles of the ball robot is the possibility of the components being damaged while rolling. In order to avoid this, a set of five bumpers are arranged around the framework. The low-friction plastic does not prevent the motors from driving the system efficiently. The bumpers also push the weight of the internal system down, keeping the center of gravity lower than the center of the ball. This helps keep the wheels and inductive coil at the bottom of the ball as it rolls and when charging.

The five bumpers are connected to screws that protrude from a 1 inch cube. Each screw has a spring. The bumper rests on top of the spring. When pushed against the ball, the bumper compresses the spring. This keeps the mechanical system from being trapped in a rigid position and able to deform based on what is needed from outside stimuli. The bumpers also protect the PCB. When rolling, there is the possibility of the PCB hitting the sides of the ball. The bumpers keep the structure, and the PCB mounted on it, in a central location that will not strike the ball. In addition, the consistent location inside of the ball allows for more precise motion.

C. Gearbox

The Tamiya twin-motor gearbox houses the motors and wheels for Puppy Pal. The wheels are controlled independently of each other because of the separate gear trains in the gearbox. This allows for steering and prevents a motor controlling the wrong wheel. The gear ratio used in this project is 58:1. The low ratio gives the wheels more torque, driving the robot with less effort.

The gearbox sits at the bottom of Puppy Pal's internal structure. With the batteries, bumper system, and PCB attached to it, the gearbox holds much of the weight of the robot. The weight pushes the wheels down to the bottom of the ball and keeps them in constant contact with the rolling surface.

Space is limited inside of the ball. To accommodate for this, the 2 inch diameter wheels that came with the gearbox were discarded and replaced with 1 inch wheels. The new wheels are half an inch in width. They are also rounded, allowing for a greater part of the surface area to be in contact with the ball's surface. These subtle differences allow for more grip and control.

D. Motor Driver

We selected the TB6621FNG motor driver to drive the pair of motors mechanically powering this device. This driver exceeds the motor voltage and current requirements, has a small footprint, and is reasonably priced. This driver has the ability to independently drive two motors based on a Pulse Width Modulation (PWM) signal and two digital signals. The PWM signal is supplied by the analog ports of the main processor and the digital signals are supplied by GPIO ports from the main processor.

E. Motor Control

Each motor is controlled independently. The 6V motors operate at different speeds to change directions. The signal from the microcontroller changes the speed of the motors based on the duty cycle of the PWM. When the user is controlling Puppy Pal, the sliders tell the microcontroller both the orientation of the motors' rotations and the duty cycle the PWM signal should have. The forward slider tells the microcontroller which duty cycle it should send to both motors. This acts as the speed control. The steering slider tells the microcontroller what the difference between the two motors' duty cycles should be. This allows for rotation while the robot is in a stationary position and turning when it is mobile.

F. Mounting

The different parts of the mechanical system were constructed in multiple ways. The metal cube, which is the center of the bumper system, was welded in a machine shop with the screws later inserted. Instead of attaching the bumpers to the screws or the springs, they rest on the springs until they are pushed down. The battery pack is superglued to both the gearbox and the metal cube. This connects the two main components of the mechanical system. The gearbox was assembled by hand. To accommodate the smaller wheels, the shafts were shortened. The PCB is atop the metal cube. This allows for close proximity to the power supply and the most protection in between the bumpers.

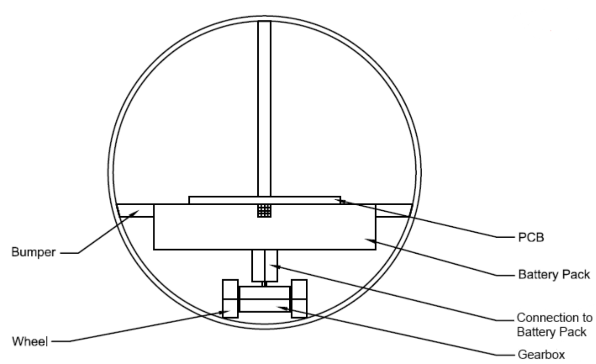

Fig. 8. Internal structure of the mechanical system

IX. 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.

X. Challenges

We have had multiply difficulties throughout the semester. The greatest delay of our progress was the mechanical system. The H-bridge motor driver we initially chose was not compatible with the Atmega2560 as advertised. Although we were able to drive the motors with it for a few days, after a weekend, the driver completely stopped working. Thinking the problem was in the code or the wiring, we spent one week troubleshooting the circuit and software and one week waiting for replacement parts. When we connected an identical driver to the microcontroller with the code and connections as the broken one, the motors worked perfectly.

Our attempts at incorporating the Microsoft Kinect into Puppy Pal were also a loss. We intended to use the Kinect to track both the ball and the dog when inside of the designated play area. However, the clear plastic made it difficult for the Kinect to find the ball. It also interpreted the skeletal structure of a dog as that of a human crouching low to the ground.

The size of our enclosure was an issue as well. When assembly began with the parts that we had successfully tested individually, we found that the 5.7 inch diameter ball we had started with was too small. The wheels that we attached to the gearbox were much too large. Instead of the wheels and the weight of the robot lying in the bottom quarter of the ball, the wheels rested only an inch below the center of the ball, leaving the center of gravity above the center. This prevented the ball from rolling correctly when the motors drove the wheels. The wheels were also so large that only the edge of the tires made contact with the wall of the ball. We switched to a larger ball and smaller wheels to counteract these problems.

XI. Conclusion

Puppy Pal represents Group 11's first dive into actual engineering. We took the idea for a product dog owners want when away and learned everything we could in the research process. We organized this information into a series of viable solutions and determined what could be accomplished within our allotted time. Parts were ordered, tested, replaced, and abandoned. We learned how to create and refine a smartphone application. We worked with Bluetooth communication for the first time, which gave us a practical understanding of serial communication between different devices. We also learned what we could to build a simple mechanical system that could drive the motion of ball from the inside and remain in our control. All of this was part of our learning experience in the engineering life cycle.

Before Puppy Pal is introduced into a competitive marketplace, the product needs to be further refined. A more compact design would be ideal for smaller dogs. The current prototype has a diameter of 6.25 inches, making it difficult for a dog to bite onto and carry around for play. At this stage, this is desirable because we can only rebuild the toy so many times. The larger size did give us more room for customization and to try different designs throughout the process. The appearance of the toy should also be changed to appeal to dogs aesthetically, not just because it moves around. Future versions of this project should consider these options and possibilities in their designs.

Acknowledgements

We would like to thank Dr. Samuel Richie, the entire faculty and staff of the College of Electrical Engineering and Computer Science, and Boeing, Inc. Dr. Richie for his guidance and support throughout the project. He was a valuable resource and advisor. The CEECS for challenging us to do more than we thought ourselves capable our entire time at UCF. We are the engineers we are today because of you. Boeing, Inc. for funding us. Their financial support made Puppy Pal, the physical manifestation of the sum of our education thus far, a reality.

BIOGRAPHY

Marshall Scott Smith III, a graduating senior receiving his BSEE from the University of Central Florida. He worked with the Substation Engineering department at Lakeland Electric, a municipal power utility in central Florida, as an Intern for two summers. Following graduation, he intends to continue his education, pursuing a PhD in Electrical Engineering at the University of Central Florida.

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Cameron Riesen is a senior at the University of Central Florida who will be graduating in December of 2014 with a B.S. is Computer Engineering and a minor in Mathematics. After graduating he plans on getting a job writing embedded software.

Anson Contreras is an Electrical Engineering student at the University of Central Florida. He will graduate with his BS in August 2014 along with a Minor in Mathematics. His interests include semiconductor devices and electronics. He hopes to find work in these related fields.

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