The Autonomous Pet Entertainment System (A.P.E.S.)

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***Abstract* — The Autonomous Pet Entertainment System (A.P.E.S.) is a device developed to entertain an owner's pets when they are too busy to do so. APES utilizes state of the art navigational optoelectronic technology to traverse many standard household environments and show laser output as entertainment for pets to chase and observe. Onboard computer systems allows the device to use computer vision learning to identify pets and navigate complex environments via computer based identification algorithms. A laser rangefinder system developed for the APES allows for precision movement via an infrared laser so as to not distract pets from the visible show laser.**

***Index Terms* — Mobile Robots, Computer Vision, Robot Sensing Systems, Laser Radar, Optical Diffraction.**

I. INTRODUCTION

Cats and humans form a symbiotic relationship that has its roots in prehistoric pest removal. Although now we view them more as companions than farm animals, cats are still highly specialized hunting machines, and this informs the way we entertain and interact them. Any small quick movement around a feline is bound to elicit a response. During these trying times, many individuals are stuck working and studying from home, and many of us have furry loved ones to keep us company. However, as anyone with pets, children, or a spouse will tell you, they require attention and can be a detriment to productivity if not appeased. However, appeasing those you care for is time not spent on productive labor, what is an engineer to do? With greater demands of productivity automation has become an ever-increasing aspect of our lives. And while self-driving cars are not quite here yet, automating our lights and vacuum cleaners is something many of us are already used to. With an increasing population of people who spend the majority of their work day at home finding ways to automate tasks can lead to greater productivity.

The device we developed is meant to decrease time the user spends entertaining their pets while also monitoring their pet autonomously. The Autonomous Pet Entertainment System (A.P.E.S.) will allow for users to monitor and entertain their pets without having to get up and do it themselves and will hopefully reduce the number of knocked over cups and stepped on keyboards. To accomplish this APES will use computer vision in the detection of the cat and optical detection to navigate its environment. The APES will allow for users to entertain their pets remotely without fear of the system harming the pet or their property. And like commercially available robotic vacuum cleaners, it will detect walls and edges using optical sensors to avoid colliding into objects. It will also report if it has been knocked over and its location back to the user, allowing users to focus on other tasks without distraction.

II. DEVICE GOALS AND OBJECTIVES

The APES is a laser pet toy where most of its design decisions come from the requisite to be unique and considerably different from the rest of laser pet toys on the market. This is a central tenet of motivation for design and many specifications. In order to accomplish this, the APES's characteristics combine and alter the characteristics of all the other various laser pet toys on the market. The primary goals of our APES is as follows:

- Utilize a highly visible show laser that can distract a pet with its erratic and spontaneous movement.
- The show laser must be capable of changing its size and its shape.
- Navigate its surroundings by avoiding any near objects which involves distance measuring.
- Use computer vision to identify the pet/or object in front of the device.
- Minimize all possible harm and make safety a priority.
- Be completely autonomous when active.

The first goal is achieved by mounting our laser on the very top of the device. where it has servos attached to it to give it a degree of freedom to rotate vertically and horizontally. The laser beam is intended to shine at a place where the pet can easily reach it which would be the floor and low portions of a wall. Its movement algorithm is designed to not follow a generic pattern and is mostly sporadic. To achieve sporadic movement, several different movement algorithms were constructed, and a random number generator to switch between them based on a time limit.

To achieve the second goal, a lens in front of the laser will move as where a motor will vary its position which changes the size of the beam. Another motor is used to control a wheel holding several diffraction patterns so when the beam passes through it, the general shape of the beam will change. These elements move with the laser as it moves.

To achieve the third goal, various IR sensors which consist of an IR LED and photodiodes were placed around the perimeter of the device so if an obstacle gets too close to it, the device will move in the opposite direction. For propulsion, it uses motors connected to each rear wheel and there must be a caster wheel in front to help rotate the device easily. For navigation, an IR laser and photodetectors are used in a laser rangefinder where object distance helps the device in navigation.

For the fourth goal, the webcam utilizes computer vision to identify an object/or pet directly in front of it and the laser rangefinder communicates that object's distance. This in turn helps the algorithm determine what its best course of action is in response to the object's specific distance. An object can be used in place of a pet since testing a real-life pet may have some complications associated with it such as the cat's behavior, availability, etc. APES is designed in thought of being able to identify a real cat or dog.

For our last goal, autonomy includes no user input besides turning it on. All of the algorithms of the device are made in mind of keeping the device completely separate from any additional help which includes its laser movement, navigation, and propulsion. Within our algorithms, there are given scenarios for our device and what the device does based on those scenarios is what will need to be tested for intended functionality. For instance, if the APES is active and we take a box and place it on the side of it, the device should be able to automatically detect it, reference its algorithm for the most relevant scenario to this case, and should follow the algorithm accordingly (move to the opposite side). The APES will need to be able to follow all the above goals and objectives completely by itself.

Our primary objectives were made to fulfill the requirements of our goals. To accomplish our goals, we will have four primary objectives:

- Detection of the environment through the use of laser range finder and LED lights.
- Detection of the pet while still or in motion via the use of webcam and computer vision software.
- Communication between sensors and microcontrollers to facilitate motion.
- Alternating laser display using diffraction gratings and a lens capable of changing the shape and size of the display.

APES uses a laser rangefinder to detect objects in the environment when autonomously navigating any environment it is placed in. The in-house developed rangefinder utilizes an infrared laser beam to detect the distance of the nearest object in the direction of movement of the toy. The system also features a pair of photodiode devices to detect said beam and report the distance back to the microcontroller to prevent the system from colliding with other objects. By using trigonometry, the APES can check where its position is in relation to the rest of the room and will use the rangefinder to measure the distance of any object in-front of it. Pairs of infrared LEDs and photodiodes are attached to the side of the APES system to aid in navigation as well. These device pairs act as an optical bumper system to assure that our system is aware if any object or person gets within range of it from the side or behind. This gives the system 360 degrees of special awareness and keeps the object from any unexpected collisions with objects not seen by the camera or rangefinder.

APES utilizes a webcam to identify the user's pets and track their motion using computer vision. The webcam will be driven by a microprocessor running the openCV software to run detection algorithms on the room around the toy. The camera takes in a video feed of the room and sends individual frames of video data back to the microprocessor via the use of the VideoCapture() function present in openCV and sends them to the microprocessor to be analyzed. The microprocessor takes the frames to determine if the cat is present in the room by running the software's CascadeClassifier class and method. The microprocessor then captures the positional data of the cat in relation to the toy. The camera communicates with a microprocessor to determine where to point the laser display in relation to the motion of the user's pet. By determining the view distance of the camera in relation to the system we then estimate the cat's position and send that data back to the system to determine which direction the laser should be pointed in. While this mode is active the microprocessor will communicate with the microcontroller to remain stationary, movement causes disruption in the detection algorithm and gives the appearance of motion where there is none. In the event the detection algorithm does not detect anything in frame to be motion tracked, the microprocessor communicates with the controller to enter into navigation mode for relocation. The camera will then cease function allowing for the preservation of power in the system. When the navigation is over the camera will be restarted and the scanning algorithm will begin again.

As mentioned, the microcontroller will read input data provided by the optical sensors to determine the position of the system in relation to its environment and move accordingly. This drives the motion of the system by having these sensors report back any obstructions in the path of the system. The microcontroller then communicates with wheels motors to begin motion by sending a pulse width modulation (PWM) signal out of the controller and to the motor. By sending a PWM signal with a certain duty cycle, time in which the signal is on, we will be able to control the speed in which the system accelerates and decelerates. By combining this with the communication with the laser range finder, the system can determine how far away an object is and begin to stop by using a formula that takes in distance and converts it to the appropriate PWM signal to send the motor. The system, if suddenly obstructed, is told to move in reverse before doing any more movement actions until there is enough distance for it to resume its normal movement routine. The system will be able to rotate in place just like a commercial vacuum cleaner and navigates the room in a similar two-dimensional fashion. Since the toy is meant to only seek out pets, the more robotic two-dimensional motion allows us to save processing power. Navigation takes place over a certain distance; in the event the distance of travel is lost it will also be on a timer before reverting back to scanning mode. During navigation, the camera will be off, and the primary function of the Jetson nano will be to do any calculations, such brake speed and acceleration, that might slow down the ATMega328. The response time of the system is maximized while in motion and minimizes the time it takes to begin scanning once navigation has been paused via optimal computer work distribution.

The primary feature of the APES is its show laser display. The display has two modes of function. In the first mode, the laser will be pointed in the same direction of the camera. The laser will be servo mounted and capable of motion along both the x and y axis. When the camera sends the jetson nano the video information it has detected, the jetson uses this positional data to calculate the location of the cat in respect to the point of view of the APES. It is then able to output to the laser servos to the angle at which the laser should be adjusted as to be in a different location than the pet, with the ultimate goal being a smooth transition of position in which the laser does not touch the subject while moving to a new position and the subject is unable to reach the laser in for any extended period of time. When not in play mode the laser will have a different set of operations. It will mimic a more random pattern of movement, while the jetson nano will be in charge of running the motors connected to the wheel gradient that will determine the pattern of the laser display during the light show and the lens motor which determines the radius of the display.

III. DEVICE LAYOUT AND SPECIFICATIONS

A. Device Design

As mentioned before, the design of APES is heavily inspired by existing commercially available vacuum cleaners. The chassis is a layered cylinder 13.5 inches in diameter which houses most components within and is constructed using expanded PVC foam board raised by bolts to an inner height of 2 inches. On top of the chassis is a clear plastic dome 6 inches high and a diameter equal to that of the chassis. There is also a 3mm EVA foam pad attached to the perimeter of the device to prevent damage to the APES or anything it might collide with.

B. Component Layout

Most components of the APES system are housed within the chassis chamber between the clear plastic dome and the bottom of the chassis. This includes the PCB housing the ATMEGA328 chip, motor driver, laser rangefinder, IR sensors, and battery. The battery being the heaviest single component is mounted in the center between the two drive wheels. This helps ensure the balance of the three wheeled design. The IR sensors are mounted to be front facing and offset from center to the left and the right. This leaves the laser rangefinder to account for the front center of the toy.

The dome on top houses the show laser display system, camera, Jetson Nano, and servo control board. The show laser display system is mounted on a raised platform at the center to allow the greatest field of view for the laser itself. The camera is fixed to a mount at the front to ensure the device can detect pets to the front of it.

The bottom of the chassis mounts a centered caster wheel in front and two motor driven wheels in the back of the device.

C. Device Specifications

Table 1
APES System Specifications

System Specifications		
Specification	Value	Unit
Vertical Laser/Camera Movement	100	Degrees
Horizontal Laser/Camera Movement	180	Degrees
Laser Wavelength (Show Laser)	650	nm

Laser Wavelength (Laser Rangefinder)	940	nm
Laser Rangefinder Detection Range	5.5 - 40	in
Laser Power (max)	5	mW
Beam Spot Size Magnification	2.5, 7.5	x
Speed	1.5	fps
Battery Requirement	12	V
Battery life (min)	5	hrs
Obstacle Distance (min)	8	in
Weight	4.6	lbs
Cost	366.30	$
Radius	13.5	in
Height	10.375	in

IV. DEVICE OPERATION

A. Propulsion

The propulsion of the APES is provided by two TT motors with 65mm wheels. These motors are driven by a Dual H Bridge L298N Motor Drive Controller. This motor driver provides a stable and reliable connection between the processor and the motors, a large filter capacitance, an after-flow protection diode, and the ability to drive two DC motors individually. There is also a built-in voltage regulator with 5V output which powers the ATMEGA328 chip.

There is also a 1.3 inch caster wheel mounted to the front of the device. With the three wheels mounted in this triangular formation and the two rear wheels being controlled independently, the APES is capable of maximum maneuverability via zero radius turns. The PCB housing the ATMEGA328 as well as the many connections to sensors and drivers is shown in Fig 1.

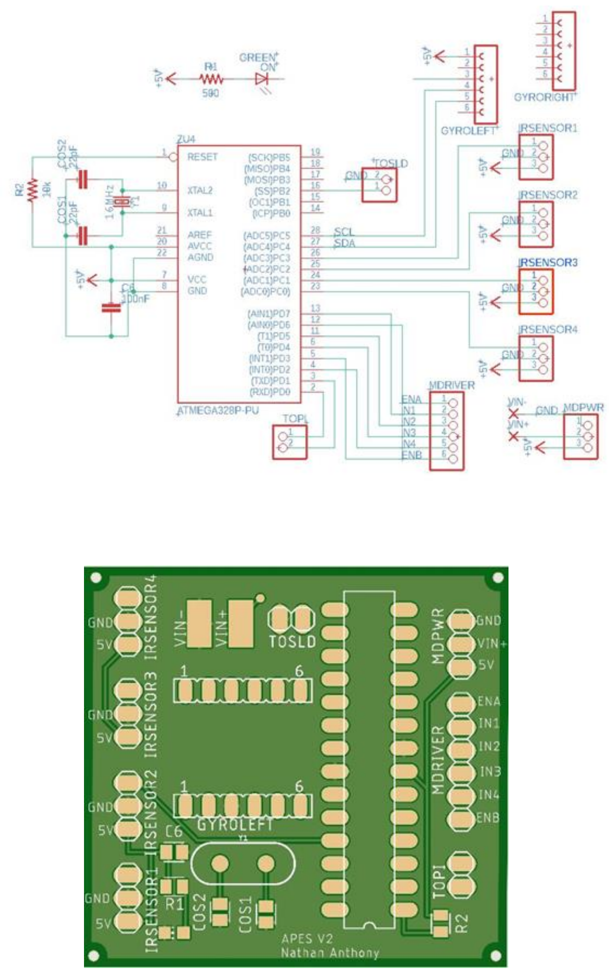

Figure 1: Final PCB Schematic and Design

B. Navigation

While the APES is engaged in its navigation mode, the primary function is simply to move forward so long as none of the sensors are tripped. Both motors are set to the same power but they are inconsistent in actual speed. This is used to our advantage in that it allows the APES to randomize its path upon activation without having to implement any specific randomization function. The randomization of the path ensures that the APES is more likely to find a pet by randomly exploring different parts of the environment.

APES utilizes four DZS Elec Infrared Obstacle Avoidance Sensor Modules. Each module contains one LED and a complimentary photodiode on a driver circuit board. This board will power on both devices and read the output signal of the photodiode. Together, the assembled pair unit will have the standard positive and negative pins along with a third pin for the signal generated by the photodiode. The signal pin will be connected to the ATMega328 for processing. These pairs will operate similar to mechanical bumper sensors except a signal generated by the photodiode absorbing infrared light is used to gage the distance from an object or surface to the APES. The LED is always emitting invisible light in front of the pair which the photodiode can detect only if an object is in front of the LED reflecting the light back towards the photodiode. When the object is close enough to the pair, the signal pin reads high.

Once one of the IR sensors reads high, the APES halts and turns away from that obstacle. The location of the sensor determines which direction to rotate: either left sensor is tripped means right rotation and either right sensor tripped means left rotation.

The laser rangefinder used on APES utilizes an 940 nm IR laser diode (Converted from a 532 nm laser) and two photodiodes sensitive to the laser wavelength in order to use triangulation as a method of measuring distance. Trigonometry distance measurements for this system require only the distance between the two photodiodes and the two angles at which the photodiodes give the highest voltage reading on their respective servo motors. The distance between the two diodes is always fixed so there is no need to calculate it. Angles of the photodiodes are acquired from operating servos attached to the diodes at one-degree increments and comparing the voltages generated by the photodiode per angle. Our IR laser diode is fixed in between the two photodiodes where it is pointed in front of the APES. The angle at which the most voltage is generated corresponds to the angles at which the photodiodes are facing directly at the tightly focused IR laser beam spot on an object in front of the system. APES controls the laser rangefinder via the Jetson nano's GPIO where the interface powers the laser, servos, and photodiodes as well as operating voltage amplifiers and analog to digital conversion circuits needed to process the photodiodes' signals.

Using the following formula, we can calculate the distance from the device to the object that is in front of it:

$$D = l\,\left(\frac{\sin(\alpha) * \sin(\beta)}{\sin(\alpha + \beta)}\right) \quad (1)$$

where D is the distance from the object to the device, l is the fixed distance between the photodiodes, α is the angle with the highest signal acquired by one photodiode and β is the angle measured by the other photodiode maximum signal. The APES is programmed to send a signal when the rangefinder reads below a specific distance. In which case there is an obstacle in front of it and it turns around.

This navigation function only runs for 15 seconds before switching back to check the camera for a pet.

C. Camera/Detection

The Apes uses the Raspberry Pi Cam Module V2 to capture image data at 1080p resolution. This resolution allowed us to take high resolution pictures in which to train our detection algorithms on the APES microcontroller without the need for separate training hardware. The Camera has an upper framerate limit of 60 frames per second allowing us to capture the necessary data to perform object detection and give our system a response time of less than a second between detection and reaction.

Image data for training was captured via a specialized library provided by nvidia that allowed images captured on the Jetson to bounded and labeled. The camera-capture functionality also allowed us to split our images into proper training, validation, and testing sets before being fed into our training algorithm to create a proper detection algorithm. The detection system itself was trained using Pytorch, an open-source library specifically designed for machine learning. The data labeled data was trained over the course of the 30 epochs in which the machine would try to detect the object in our test data set and record which iteration of the algorithm performed the best. It would then export the appropriate engine file for our TensorRT development environment to translate into data we could act upon in the python script.

Our detection algorithm was designed by calling upon the engine to detect our subject in an image frame and report back to us a bounding box based on the location of the subject in the frame. We could then use the area of the bounding box to determine how close the subject was while using the position of the box in the frame itself to determine whether the subject was to the left or right of the machine. These coordinates would then drive the motion of the show laser by coordinating these parameters with specific angles on the show laser's servos.

C. Show Laser Display

At 2.5 inches long to have a free range of motion under the plastic clear dome, The show laser is placed at the apex of the APES and is mounted on two servos for 180 degrees of horizontal rotation and 100 degrees of vertical rotation. The show laser's components consist of a red 650 nm laser diode, a variety of diffraction gratings, and 2 additional servos to operate them.

For the laser diode, a servos has a gear in contact with another gear attached to the collimating lens of the laser diode. This is to shift the lens which alters the beam, expanding its size and increasing its divergence angle. The beam size has a single variable magnification (measured at an approximate distance of 28 inches) of 2.66x which has a divergence angle of 0.64°. The divergence angle value is the main priority of our design as when they get too large, the beam becomes non-planar for our diffraction gratings (output pattern won't work) and too dim to be seen. It is to be noted that this is not the case for the final version of our product which will be explained in section 7 Challenges in Development.

For the diffraction grating wheel, a servos is attached into the middle of the wheel with three gratings evenly spaced angularly so only one at a time will be aligned with the laser diode's beam. The servo shifts to each grating for its unique pattern. The diffraction gratings in use are: a 1000 lines per mm single axis grating, a 13500 line per mm double axis grating, and a special grating that outputs a "heart-shaped" pattern.

The output beam of our show laser was designed to be unique compared to other pet toys so several distinct patterns will be operable and they will be switched through every few seconds. The diffraction grating patterns will be used for the two types of magnification. There are 6 possible combinations of gratings with beam sizes, and it is best to keep them all despite that a few are not of our preferred quality. For instance, the heart grating image deteriorates at the large magnification because the higher divergence angle affects the "more complex" heart grating (compared the single and double axis grating). This is due to near-field optics where the diffraction grating patterns stop working due to the wavefronts being non-planar.

V. Device Performance

A. DZS Elec Infrared Obstacle Avoidance Sensor Module performance

Sensors on average were not as sensitive at closer distances than the manufacturers claim (0.787 in - 11.8 in) but tended to exceed the specification on the farther distance. Since the intended use for these sensors is to be in the 6-8in range, all sensors work as needed.

B. Laser Rangefinder Accuracy

Figure 2 shows the performance of the built laser rangefinder operates with fairly low percent error at long ranges with a width of 5.5 in between photodiodes. Results stayed consistent when the system was still assuring that the system can produce precise results as well.

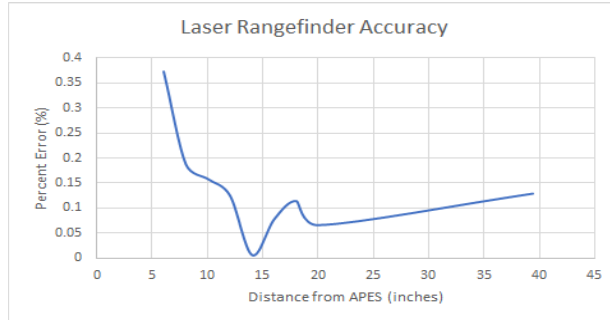

Figure 2. APES Laser Rangefinder Accuracy testing results show that the final design can measure with relatively low percent error up to 40 inches away.

VI. Safety and Logistics

A. Safety Precautions

Every product needs to conform to the standards that have been set for similar systems. This is in part to ensure the safety of the product and to ensure the smooth transition from the design and prototyping phases to the manufacturing phases of the product's lifespan. The APES project was no exception to these governing standards.

With APES being a laser focused project, it was important to research guidelines and develop with them in mind. The American National Standards Institute (ANSI) has developed four broad classifications of lasers based on their potential biological damage. The lasers will fall into these classifications based on parameters such as wavelength, average power, and exposure time. Severe and irreversible biological damage can happen from lasers if we are not careful enough. Knowing these constraints, the lasers used on APES fall under class 2 lasers which have limited output power of 5 mW. This class of laser will prevent any permanent eye damage if retina contact of laser light is to occur to either people or pets.

B. Budget

The APES project was initially proposed to have a budget of $600 for materials. Once all the parts required were assembled and tested on the final device, the budget table below was formed. The total cost of the APES system in the final version was found to be $366.30. This is $233.70 below or initial proposed budget.

Table 2
APES Budget Diagram

Part	**Amount**	**Vendor**	**Cost**

Jetson Nano 2 GB	1	Amazon.com	$60
Arduino UNO	1	N/A	N/A
Dorhea Raspberry Pi Cam	1	Amazon.com	$9
DC Gearbox TT Motor	2	Adafruit.com	$5.90
L298N Motor Drive Controller	1	Amazon.com	$8.69
SG90S 9g Micro Servo	6	Amazon.com	$14.88
PCA9685 16-Channel 12-bit PWM/Servo Driver	1	Amazon.com	$13
GHH PT Pan/Tilt Camera Platform	1	Amazon.com	$8.49
AD620 Millivolt/ Microvolt Voltage Amplifier Module	2	Amazon.com	$13.98
ADS1115 Analog-to-Digital ADC PGA Converter	2	Amazon.com	$7.99
Uxcell 5mm Round Head Receiver Photodiodes	2	Amazon.com	$3.80
SupremeTech Acrylic Dome – 12”	1	Amazon.com	$49.00
Tyseam 532 nm Green Stage Laser	1	Amazon.com	$22.69
650nm Laser diode	1	Amazon.com	$6.00
Chassis material	2	Lowes	$46.00
TalentCell Rechargeable 12V 3000mAh Lithium ion Battery Pack	1	Amazon.com	$24.79
Misc. Hardware/ Supplies	N/A	Lowe’s and Home Depot	$72.09

VII. CHALLENGES IN DEVELOPMENT

In addition to the current navigational tools, the APES originally included a gyroscope module which was exempted from the final prototype. This was done mostly in part to the module causing various computer system errors. It was found that simply removing the gyroscope from APES resolved all issues found during system integration. The original purpose of the gyroscope was to act as a safety measure for the chance that the APES was flipped. Ultimately we were comfortable removing the gyroscope due to the size and shape of the device making inversion very unlikely without the utter destruction of the toy. The most likely time for the toy to flip would be during navigation so we elected to have the show laser deactivated any time the APES moves.

APES’s laser rangefinder underwent a redesign in development. The laser rangefinder was initially proposed as a time-of-flight rangefinder system arrangement rather than the final triangulation system. Time-of-flight measurement was dropped simply due to the on-board computer’s limited processing power and project budget. This measurement system would require terahertz scale processing which neither the Jetson nano or ATMega chip could handle and the costs for the required hardware was beyond APES's financial and power budget.

Using the triangulation arrangement posed a new challenge that the time-of-flight system did not face: package size. Our triangulation system design faced a fundamental accuracy limitation caused by the distance between photodiodes. The distance between the two sensors is a fixed distance required for the calculation of distance from the system to the object it is facing. Testing revealed that photodiode distances limited the range of distances the system could read accurately. The further spaced the photodiodes are, the more accurate it becomes at large ranges but more inaccurate at close ranges. Results showed that the opposite is true with shorter diode spacing yielding high accuracy at close range with low accuracy at long ranges. This result meant that the accuracy of the rangefinder was limited by the package size that could be implemented on the APES. Despite this limitation, a fair spacing of 5.5 inches was utilized to allow max percent error of 20% at 40 in away from the device.

The show laser display was completely redesigned in the production of the prototype. Our first show laser system utilized a 532 nm green laser that used 3.7 V rather than the final 650 nm red laser using 5 V. The original show laser tube system featured a system of multiple lenses similar to a Galilean telescope arrangement opposed to the final single convex lens. These changes were done to minimize the show laser tube length from 6 in to 2.5 inches in length. This compact design allowed for the replacement of a stepper motor to another servo motor needed to move lenses in the telescope system and less strain on the servo motors in the mount. Additionally, this was to make the show laser system lightweight and compact to fit on the servos mount. While these changes limited the magnification abilities of laser display, the changes brought more benefits than negative to the project. Our show laser's diffraction wheel was redesigned as well. Initially a full sized wheel, the wheel was changed to a semicircular shape for better compatibility with the servo motor and more compact final package.

On the subject of magnification due to translating the collimating lens of the laser diode, it was possible to have 3 distinct magnification sizes similar to our original design as opposed to only two. After being tested in a lab, the 3 possible magnifications were 1x, 2.5x and 7.5x with divergence angles of 0.24°, 0.59°, and 1.78° respectively. While it did not reach up to 21x, these were distinct enough to be seen as separate sizes even at several meters. The limitations that hindered our ability to use said magnifications were servos rotation and mechanical knowledge. The servos can only rotate 180° which can shift the gears to move the collimating lens only a finite distance. In our case with our particular 3D-printed gears, this only leads up to 2.66x magnification which we used. To circumvent this, the gear ratios would have to be changed from its 1:1 ratio to a proper ratio while considering the gear size and its plausibility of being 3D-printed (the files of the 3D-printed gear of the servos were found online). To be able to construct and assemble the exact gears required us to know much more mechanics than we knew at the time, and was abandoned due to having a limited time to finish it. Several of our initial software algorithms were heavily reduced and simplified for our show laser's movement. The algorithms were redesigned to fulfill our goals and objectives in very basic cases. For instance, our algorithm initially included laser movements when the animal/cat was not in vision of the camera for tracking. Now the show laser is stationary when the animal/cat is not in vision and it only moves when the animal can be tracked. This is a software reduction that does not hinder our project's objectives as the algorithms were made for our autonomy goal, which only needs to have a basic function.

The voltage regulator that was originally included in the PCB ended up being removed from the final design. This was due to the fact that the design generated by the TI WEBENCH power designer was not functional as depicted in the TI simulations. Our own LTSpice simulations supported the physical characteristics of the assembled regulator. Time constraints dictated that we remove the regulator from our device and use the 7805 regulator already used by the L298N Motor Driver to power the ATMEGA328.

VIII. CONCLUSION

Despite the array of pivots and limitations APES's development cycle faced, a working prototype was produced. Said prototype meets the goals and objectives originally set out in the proposal for the project. Few features initially set had to be cut to produce a working prototype. Additionally, the project met the proposed fiscal limitation, limited development time, and operates effectively. For future development and improvement of APES, more financial resources, engineering personnel and time should be allotted to allow better built-in hardware, higher production quality, and potentially more device features.

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