The Autonomous Returning Chair (A.R.C.)

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The objective of this paper is to cover the strenuous details of our automatically returning chair from the heavy implementation of computer vision for object tracking as well as motor movements to carry out instructions sets through a method of serial communication. Other details covered are power transfer and conversions, chair functions and design, the motor system and design, and microcontroller selection and functionality. Each piece of information is meant to provide reasoning as to why these components and functionality were selected and designed.

***Index Terms* — Automation, Computer Vision, Object Avoidance, Voltage Regulation, PCB**

I. INTRODUCTION

The automatically returning chair or A.R.C. for short is designed to alleviate the poor habit of leaving chairs in disarray or disorder. This issue is commonly observed in an office environment or meeting rooms. Cluttered environments are hazardous as someone could easily trip over misplaced objects and injuries may occur as a result.

To address this, the A.R.C. autonomously returns to a set destination point when it recognizes when a user has been absent for a long period of time. It is capable of searching and locating its destination, avoiding obstacles along the way. Upon arriving at its destination, the device enters an idle state.

During the duration of time when a user is seated in the A.R.C., the device operates in a user-controlled state, providing a free range of motion for the user and behaving like a standard office chair.

II. PRINTED CIRCUIT BOARD

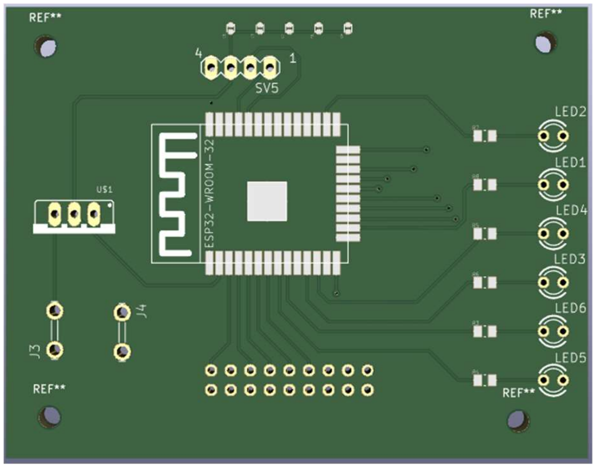

Figure 1: ESP32 Motor/Power Board Rev. 1

The initial design of the printed circuit board was that of solely a power regulator and the ESP32. The purpose of our printed circuit board is to convert a 5-voltage input and distribute a 3.3-voltage output to the ESP32. The ESP 32 would then be used to send out instruction to the respective motor controllers to perform movement tasks such as, moving forward, backwards, and rotate. When the physical board arrived, we encountered several problems such as missing boot loading and enable buttons, missing status LED, and improper power protections. These problems cause the printed circuit board to not work, and ultimately lead to a team decision to design another printed circuit board which would rectify the current problems that we were facing.

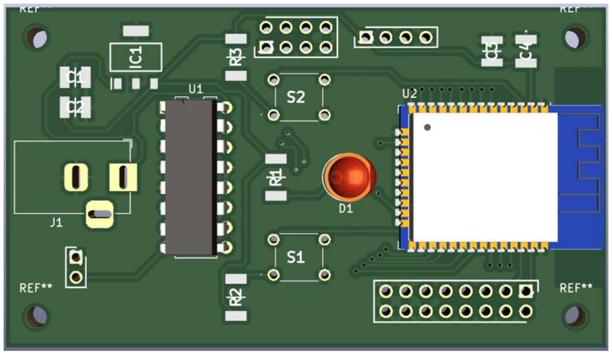

Figure 2: ESP32 Motor Board Rev. 2

The general purpose of the second PCB was similar to the initial PCB but every component was replaced with the only similarity being the ESP32 microcontroller. The six indicator LEDs on the right were replaced by a single indicator LED that simply tells the user when the circuit board is receiving power. The PCB was designed so that the power and logic components were together and separated to the two sides of the board. The ESP32 was positioned on the edge to ensure maximum distance from the power which provides minimal interference of the antenna, pictured in the blue box. Two decoupling capacitors were added and are placed close to the input of the ESP32 to reduce noise and to keep the voltage stable. The boot loading and enable buttons were added to allow the ESP32 to be flashed properly. A significant addition to this revision of the PCB was the use of the L293D motor driver to accommodate the third motor that was recently added to the project for the pully system. The regulator was also adjusted to 1.5A for the increased power requirement. The changes made to the revision provided the fixes that were needed for proper operation of the A.R.C.

III. DUAL FUNCTIONALITY

There are two main modes that the A.R.C. operates in. The first mode occurs while there is a user seated in the chair. All autonomous activities are suspended, and the device behaves as a standard office chair. This includes providing a free range of motion to the user.

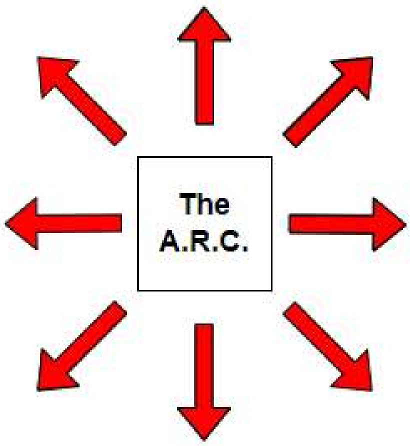

Figure 3: Directional Capabilities While User Is Seated

The other mode engages once a user has left the seat. After a certain amount of time, if the user has not returned, the A.R.C. begins its autonomous mode. It begins searching for, locating, and navigating towards its home destination. If obstacles are encountered along the way, the A.R.C. can pause its search routine, navigate around them, and then continue to progress towards its destination. A visual of this movement is shown in Figure 4. Upon approaching the destination, the A.R.C. will come to a halt once it is within an acceptable distance from its goal. It will continue to remain at rest until the user returns and the autonomous mode is disengaged.

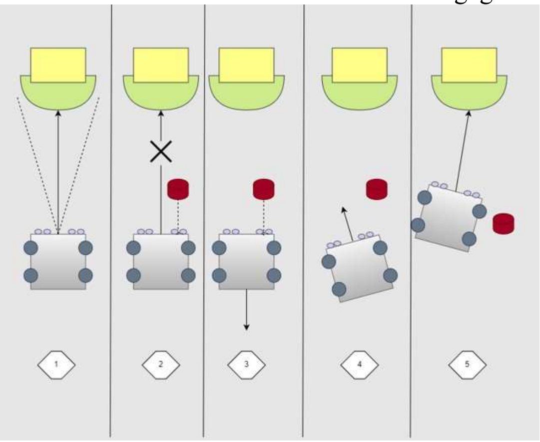

Figure 4: Obstacle Dodging Movement

To determine if a user is present in the seat, a pressure plate on the seat was implemented. This sensor is connected to the microcontrollers and determines which mode the A.R.C. is operating in. To swap between the two modes, a platform lift feature was implemented to raise the motorized wheel system while a user is seated, allowing for the caster wheels of the chair to enable the free range of movement. When the user leaves the seat, the lift lowers the motorized wheels to allow for them to be used during the A.R.C.'s autonomous mode. This lifting system is realized through a motor located on the underside of the chair. It retracts or extends a length of cable that is attached to the wooden container through four points of contact located at the same location as each of the chair leg holes of the container. Figure 5 below depicts a visual for how the container is attached to the chair as well as how the pulley system is placed.

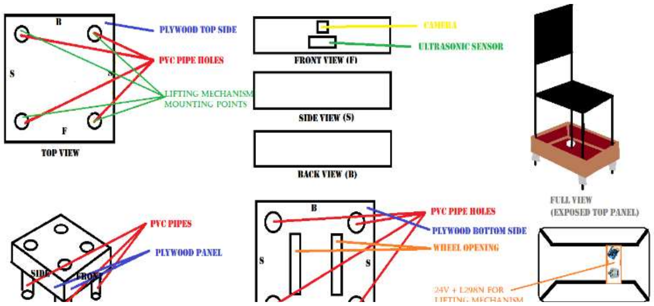

Figure 5: Wooden Container Labelling and Lifting System Layout

IV. CHAIR DESIGN

Specific considerations were considered when designing the hardware layout of the A.R.C. Unquestionably, the chair must be capable of seating a user. We planned to minimize the amount of exposed electronics in our design by providing a large housing compartment to hold most of the electronic components. In addition, a method to swap between the two wheel systems to support both functionalities of the A.R.C. must be realized.

To conserve resources, we elected to utilize a premade office chair and incorporate additions and adaptations to fit our design needs. The office chair provided caster wheels that supports the desired free-range movement for a user. To enable autonomous movement, space to house the sensors, microcontrollers, and the motor system of the A.R.C. was needed. An office chair with legs that are kept separate and did not merge in the center was chosen to suit this need. The chair chosen is shown in Figure 6 below.

Figure 6: The Selected Chair

All the electronics described were housed in a wooden construction placed beneath the seat of the chair. The wooden housing was created by laser cutting two planks of wood. The outline for the laser cut can be seen in Figure 3 below.

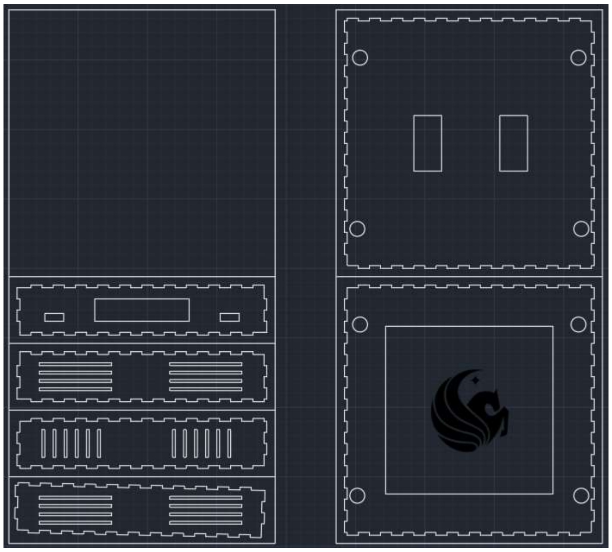

Figure 7: Wooden Housing Laser Cut Outline

On the right are the outlines for the top and bottom of the wooden housing. Both include four holes to allow for the chair legs to pass through. The bottom panel also includes two holes for the motorized wheels of our design. The top panel contains a removable panel to allow for access to within the container. On the left are the laser cuts for the side panels of the wooden container, with long strips removed on three of them to allow for air flow through the housing. The front panel contains three openings for the two ultrasonic sensors utilized in object avoidance and the camera used in locating and tracking the destination of the A.R.C.

A jigsaw-like indentation pattern was implemented along the edges of each side of the container. They allowed for guaranteed alignment when putting the container together and improved the stability of the wooden container in combination with the glue applied along each of the indentations.

V. HARDWARE LAYOUT

Aside from the component used to act as the pressure plate for the A.R.C., all electrical components are housed within the wooden housing described in the previous section. This includes components for the motor system, the microcontrollers, the sensors, and the power bank. Their placement within the container were determined after factoring in optimal location for functionality, weight distribution, and necessary proximity to other components.

The wheels, motors and motor driver used for autonomous motion are placed in the center of the container so that all movement and motion generated originate from the center of the A.R.C. The motor driver is in the exact center of the container with the motors spaced horizontally outward to the left and right side panels. These motors are mounted underneath the container, connecting to gearboxes on each side that connect to the wheels. The remaining motor and motor drivers are located outside of the container, mounted to the underside of the chair seat to raise and/or lower the container as needed (See section VI "Motor System" for details).

The camera and ultrasonic sensors are mounted on the front panel of the container to perceive and relay information to the microcontrollers. The microcontrollers, composed of the Raspberry Pi and the ESP32, is located close to the front, between the motors and the sensors.

The hefty power bank of our design is also placed towards the back of the container to counterbalance the numerous components placed towards the front. A top-down view of the components within the container is shown in Figure 8 below.

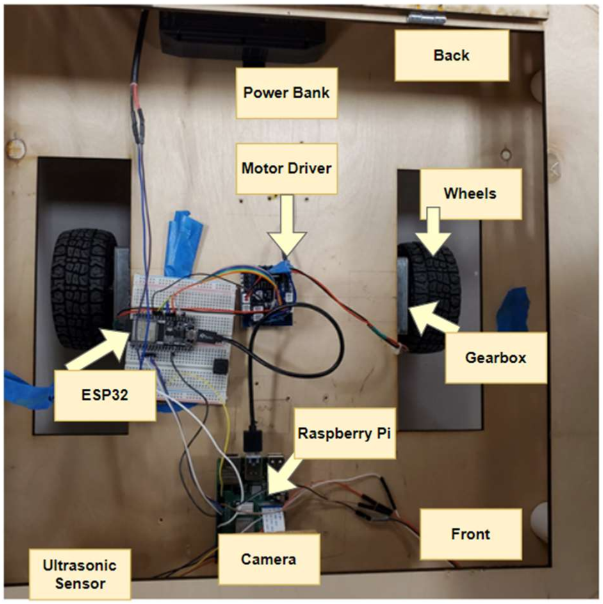

Figure 8: Components within Housing

VI. MOTOR SYSTEM

Our motor system consists of three motors and two L298N motor drivers, which each have different functionality. For movement the team has opted to connect two gearing motors to a single L298N motor controller. These two gearing motors were used to move the A.R.C. in any given direction ordered by the ESP32. After testing different types of wheels, the team has decided to use 1.81inch wide rubber wheels, these were chosen to ensure that there would be enough traction for the wheels not to slip. To allow for free movement from the gearing motor when the user is present, the A.R.C. is equipped with a lifting mechanism powered by a 24V motor connected to a separate L298N motor controller. The purpose of this 24V motor is to lift the A.R.C. off the floor when a user is seated, and to lower the A.R.C. on the floor when there is no user present. Figure 9 below shows the motor and motor driver of the pulley system that will lift and lower the wooden housing.

Figure 9: Motor and Motor Driver Pulley System

After having come across an error with the initial lifting design, the team was forced to adopt a new design. This new design is realized by elevating the seat of the chair on top of several cushion foam pads, which will compress when a user is seat, pushing a fixed rod down while pulling the A.R.C. up via the use of a pulley.

Figure 10: New Pulley Design

VII. Sensors

As previously stated the A.R.C. is fitted with two ultrasonic sensors, located at the front of the device. The team has opted to use the ultrasonics sensors for its depth perception functionality which will be used to measure distance between the device and any potential object that may appear in its path. The ultrasonic sensors are programmed to measure distance continuously as the device is ON, when either of the two ultrasonic sensors indicate a measurement of less than 10 inches, then the A.R.C. will initiate its dodging algorithm.

Placed in between the ultrasonic sensors is the camera that will communicate with the Raspberry Pi to identify the destination of the A.R.C. It will continuously monitor the area in front of the device to detect if the destination is present. If it is, the destination will be communicated to the Raspberry Pi

The A.R.C. is also fitted with a force sensing resistor, located on top of the seated cushion of the A.R.C. This sensor activates when weight is applied hence the ideal location to place it would be where the user will be seated. The team has opted to use the force sensing resistor as a confirmation system to turn the A.R.C. ON or OFF.

VIII. Power System

The A.R.C. is powered by 2 separate power-banks. The motors are powered by a 24V power-bank, which supplies a 24voltage output to the motor controller, which in turn provides power to the gearing motors. The second power-bank is a 5V power-bank, which is used to power the Raspberry pi by emitting a 5voltage, 3amp output to the Raspberry pi. Finally, the Raspberry pi is then used to output a 3.3voltage, 1amp current via the use of USB to power the ESP32 found in our significant PCB.

Our Final Design will consist of two 12V, 2000mAh batteries, which will be connected in series to provide us with a 24voltage output capability. We will use the 24voltage output to power the motor controller which in turn will provide power to the gearing motors. We will also run the 24voltage output through a 24V to 5V buck converter, to generate an output of 5V, 3amp to power the Raspberry pi and our printed circuit board. Our printed circuit board is integrated with a 5V to 3.3V converter which will be used to provide the correct 3.3v, 1amp charge needed to power the ESP32.

IX. MICROCONTROLLE0R

Our selected microcontrollers for this project are the Raspberry Pi 4 Model B as well as an ESP-32-WROOM-32D. Each of these devices are programmed in the Python language with the Raspberry Pi programmed in the full structure of Python, and the ESP-32 programmed in a lighter version known as MicroPython. Although the ESP-32 may be programmable in an alternative language such as C, programming the device with Python instead allows for the ease of debugging and writing between the devices. The decision to select these components originated from the existing understanding of Python amongst the team. Python also contains modularity in terms of a variety of libraries and can be easily integrated into the chair's design.

The Raspberry Pi was mainly used as the heart of our project carrying out tasks of testing, development, and for actual use in the final design. During testing, programs were written to test individual components such as variable motor speeds, camera vision, ultrasonic sensors, and user inputs. At development, code was written with the Raspberry Pi since many libraries functioned with the Raspberry Pi especially with general purpose input and output pins. While also acting as a development board, the Raspberry Pi is also integrated into the final design due to the requirement of the Open Computer Vision Python library requiring an operating system to run.

The ESP32 from Espressif Systems is a microcontroller mainly used to carry out instructions from the Raspberry Pi through serial communications. Like the Rapsberry Pi, the ESP32 is programmed in the Python language in a lighter form known as MicroPython. The language utilizes all the same syntax as regular Python, however, there are lesser libraries available. Though this may be detrimental, the functionalities the chair requires from the ESP32 is minimal. The ESP32 functions to capture serial data from its general-purpose pins, receive a set of instructions, and carry out mechanical tasks. Due to the number of sensors occupying the Raspberry Pi, utilizing the ESP32 was deemed necessary. Although mechanical functions may solely be completed on the Raspberry Pi, the ESP32 currently acts as an extension and noticeably reduces strain such as power draw and heat generation.

X. Testing Processes

Testing is the most important requirement for any project to ensure functionality of components and designs. There were three models designed for this project with each design carrying out certain purposes and an upgrade to the previous fixture. Titled Mark I, II, and III, each design tested a specific feature of our main robot from basic motor and wheel movement, object tracking, and even weight handling. The next images cover the designs made for our robot.

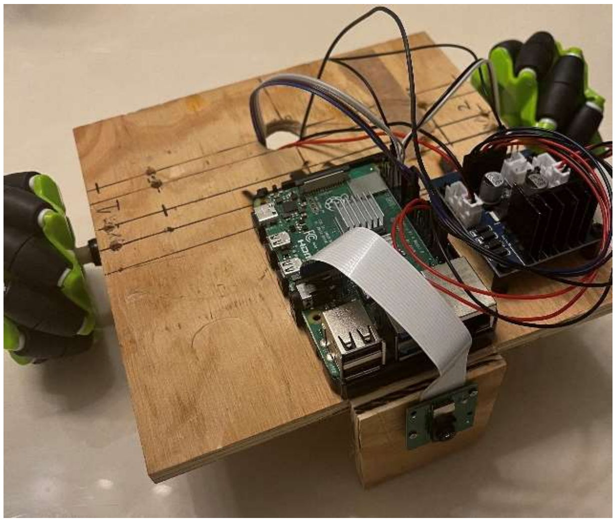

Figure 11: A.R.C. Mark I

At our initial design labeled Mark I, we tested numerous functionalities from motor movements such as moving forward, backward, left, and right as well as a camera to test computer vision to perform automatic movements based on the system's view. This first design was our most important since this fixture became our foundation for future builds. Most of the base code in the final design was written at this initial design. Mark I can perform automatic object tracking and motor movement to reach specified locations in its vision. Due to its size, and available space, this fixture was not able to have additional features such as a larger battery, ultrasonic sensors, and larger wheels were not able to be implemented for the initial design. Moreover, testing the fixture with a chair was not possible due to weight of the chair. After completing the foundational task of testing our required components, a secondary test design was set to be created.

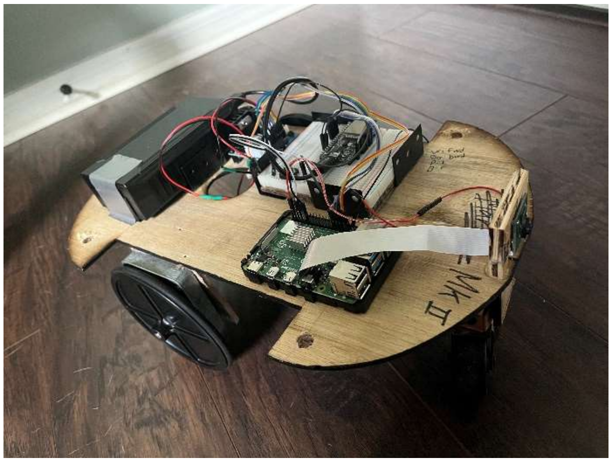

Figure 12: A.R.C. Mark II

This secondary design of the A.R.C. took most aspects of the previous design. As shown, the robot has been upgraded with a larger fixture, stronger wheel and gearbox system, a battery with a lengthier life span, and most importantly, the integration of the ESP32. Initially, the basic functions that were tested on the initial model were also tested on Mark II. This is to confirm full functionality with newer and upgraded components. New code was also written that allowed for serial communication between the ESP32 and the Raspberry Pi, as well as defined scripts for the ESP32 at any possible event. The ESP32 was programmed with movement scripts along with scripts to read any inputs and instructions received from the accompanying Raspberry Pi. As such, the Raspberry Pi was programmed to only generate instructions based on sensor data and camera vision data.

The second design underwent significant changes and updates, which was Group 44s goal when creating each fixture to reduce creating unnecessary designs taking up time and resources. Additionally, with the upgraded components such as the wheel and battery, this fixture can move a chair to various locations without any problem caused by weight. In the next design, the tertiary design went for changes in stability and cosmetics. Although the Mark II successfully functioned with all our intended scripts, a third Mark is necessary for visual appeal and a more stable design.

Figure 13: A.R.C. Mark III

The third and final design is the A.R.C. Mark III, which currently carries out all the previously tested functions from previous design. The key change in our design is a fixture measured to fit our selected chair smoothly with a highlight to the cosmetic features. The design, as shown, is an enclosed box with a sensor array at the front, a lid for electronics access, and side openings for airflow.

XI. Code Design and Algorithms

The A.R.C. was mainly programmed in the Python language due to the programming language's modularity for robots with a vast library of existing function definitions. Like the physical hardware designs, there were three programs written with each being an improvement of the previous program.

Initially, the first program was written with numerous test functions to ensure peripheral devices functioned properly before moving into a more complex build of the code.

At the second program, code was written integrating aspects of computer vision and motor functions. This program utilized an approach of iterative instructions with timed delays.

The final program, or the tertiary code structure, served as the major improvement to our code structure. During testing of the second program, many problems pertaining to timings were found when preforming a series of potential user events. The solution found was to use a method of polling to act as a form of interruption based on user input events. The code utilized a timer that periodically resets if a user is found during the polling phase at the rate of 10 milliseconds. Upon reaching the maximum time of 5 minutes during user absence, the program then runs the home locator.

The two algorithms written into our automated robot are the locator and dodge routines which functions in tandem with each other through the previously described method of polling.

The locator algorithm implements computer vision to calculate the location of the home base. From there a path is generated to reach its destination and can be periodically changed during its travel. The dodge algorithm is also implemented where the chair can adjust itself accordingly if an obstacle is present in the path of the chair. The ultrasonic sensor is responsible for determining those foreign objects.

XII. Finances

The team was able to achieve this design slightly over their expected $600 dollar budget. This budget was a constraint from being a self-funded group, however, this budget was calculated with the intent of salvaging and re-using of certain components that were already available to the group. The group slightly underestimated some miscellaneous costs which ultimately lead to us being over our expected budget.

Item No.	Name	Quantity	Cost per Unit	Total Cost	Seller
1	2 Pcs 550 35000RPM Electric Motor for 24 Volt Kids Ride On Car, RS550 24V Motor Ge	1	$26.98	$26.98	Amazon
2	TalentCell 24V Lithium ion Battery PB240A1, Rechargeable 22400mAh 82.88Wh Li-ion	1	$69.99	$69.99	Amazon
3	EVAL BOARD FOR ESP-WROOM-32	1	$10.00	$10.00	Digikey
4	BREADBOARD TERM STRIP 3.40X2.20"	1	$5.00	$5.00	Digikey
5	JUMPER WIRE F/F 6" 20PCS	1	$1.95	$1.95	Digikey
6	JUMPER WIRE M/F 6" 20PCS	1	$1.95	$1.95	Digikey
7	JUMPER WIRE M/M 6" 20PCS	1	$1.95	$1.95	Digikey
8	Arducam 5MP Camera for Raspberry Pi, 1080P HD OV5647 Camera Module V1 for Pi 4	1	$9.99	$9.99	Amazon
9	Raspberry Pi 4 Starter Kit	1	$139.95	$139.95	CanakKit
10	FSR402	1	$11.67	$11.67	Digikey
11	Black Mobile Desk Chair	1	$71.63	$71.63	Home Depot
12	Gearhead Motor With Wheel	2	$9.95	$19.90	SkyCraft
13	Dozen 10-32 9/16 Flathead Screws	1	$0.25	$0.25	SkyCraft
14	Plywood Plank	1	$9.95	$9.95	Lowes
15	1/4 2X4 Birch Plywood	2	$19.56	$39.12	Home Depot
16	1" X 10' PVC Pipe	1	$5.96	$5.96	Home Depot
17	Osoyoo Mechanical DIY Robot Kit	1	$76.64	$76.64	Amazon
18	Pcb rev1	1	$10.86	$10.86	JLPCB
19	Tenergy 2 Pack 12V 2000mAh Battery Packs RC Battery w/Bare Leads for RC Airplanes, RC	1	$42.79	$42.79	Amazon
20	Adjustable CC CV Buck Converter Power Supply Module 12A 160W DC to DC 5.3V-32V	1	$18.06	$18.06	Amazon
21	pcb components	1	$23.08	$23.08	Digikey
22	pcb rev2	1	$15.86	$15.86	JLCPCB
23	pcb components	1	$22.07	$22.07	Mouser
24	PR Racing SCT-P006 2.2"/3.0" Short Course Truck Tires with Foam Inserts & Black Wheel Rims 12mm Hex 2Pcs	1	$21.99	$21.99	Amazon
	Grand Total:			$657.59	

Figure 14: Itemized Expenses

XIII. Conclusion

After all components had been purchased, tested, and installed, the team was left with a working device that was able to utilize the power of computer vision and various sensors such as the ultrasonic sensor, and the force sensing resistor to return to its home station when moved away. The final design can self-sufficiently and efficiently return to its home station while avoiding any object that may appear in its path.

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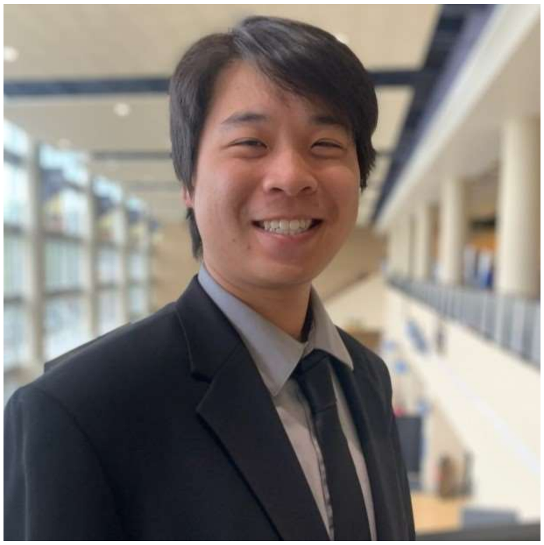
Biography

Lyons Opina - Bachelor of Science in Electrical Engineering - Team Lead and Programmer – Senior student graduating May 2022 and acting as team lead for group 44, The Chairmen. Main role is to delegate tasks, strategize meetings, as well as maintain responsibility for programming onboard microcontroller devices. Currently interning at a power electronics corporation, upon graduation, Lyons intends to pursue a career in renewable energy.

Eric Le – Bachelor of Science in Electrical Engineering – Senior graduating Spring 2022. Currently working as an intern in power electronics. Eric's role in the team is to design the PCB and the 3D cad models.



Tony Du – Bachelor of Science in Electrical Engineering – Senior student graduating in July 2022. Currently working as a co-op at Philips Healthcare, Tony plans to pursue a career developing new attractions at one of the local theme parks in Orlando Florida.

Daniel Nouh-Chaia – Bachelor of Science in Electrical Engineering – Senior student graduating May 2022. Post-graduation Daniel plans on returning to his home country of Suriname to pursue a career in smart home developments.