Golf Ball Search and Rescue

Group 31 (Gold Team)

Spring/Fall 2021

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Project Overview

Project Description

Work as a team to design and build a successful project that meets/exceeds the goals and standards set forth. Challenging knowledge, creativity, communication, and work ethic at each step to grow and accomplish greatness together. Specifically, design and build a fully autonomous device that can identify and retrieve golf balls scattered throughout a field. The team will work together to achieve the best product possible. Furthermore, our completed device will compete amongst three other teams completed projects. Competition goals will include the amount of time it takes to retrieve golf balls and the total amount of golf balls collected. Success in this project will show dedication and teamwork that will provide a foundation that can lead to career opportunities.

In this project, our team will produce an autonomous vehicle that will be capable of golf ball retrieval and golf ball drop off within a certain area. The mechanical engineering students will be tasked with the design of the autonomous vehicle and the computer science students will be in charge of the software that will be backing the implementation of our vehicle. Both parties will have to work together in harmony and develop strong communication skills in order to seamlessly incorporate intelligence into a suitable vehicle.

Statements of Motivation

Alexa Keene:

This project was my top pick when I was selecting what I would like to do for senior design. I knew immediately that I wanted to be involved in this task of creating and programming an autonomous vehicle because I have a great interest in autonomy. I think independent robots, such as the Roomba, the Litter-Robot, and self-driving cars are amazing inventions that are paving the way of our future technologies. I want to be a part of this ground-breaking technology.

Additionally, I also view this project as extremely challenging. It is very unlike any project I have ever participated in before. To create a successful device, I will have to do immense research and as a result become more knowledgeable on the topics of autonomous robotics, robot vision, and artificial intelligence (to name a few). As a result, besides gaining information, I will be more prepared for real world applications that I may be presented with following after graduating. I believe this project will be a launching pad for me into a successful career.

Andrew Tsai:

I have always had a desire to learn and to be put in scenarios that will challenge me and build my character. I enjoy working in a team-based environment because it builds my interpersonal skills, an essential ability in the software development industry. Golf Ball Search and Rescue seems like a daunting project, but the fact that I am able to be part of a team that will be designing an autonomous vehicle from the ground up sounded like a major accomplishment that I will be proud of. It is my belief that there is always room for improvement as there is so much to learn in the world of computer science, and I am excited to take my first steps in machine learning, image processing and multimodal sensor data synthesis for target acquisition.

Furthermore, competition is another key factor for my motivation. Golf Ball Search and Rescue is the only senior design project that incorporates a competitive scene, and, with that additional factor of finding creative methods to collect golf balls faster and more efficiently, further drives me towards the path to success. Projects may start to get a little mundane if there are no rivals there to keep you on your toes. We all want to be the best of the best for this competition project, and with this motivational element, I will be able to push myself and my team further into creating a well-optimized autonomous vehicle that will satisfy my competitive spirit and thirst for learning.

Jimmy Cabrera:

To be completely honest this was not the first project that grabbed my attention, I had other ideas in mind when I first looked at the list. The first project that I was interested in was the manta ray tail. My whole life I have had a passion for cars, and have raced since I was 5 years old which is why love competition. As a young kid I loved building legos and disassembling/assembling anything I saw.

After thoroughly reading all the projects without a doubt this one most aligned with what I like and what I hope to become as a mechanical engineer. I really liked the idea of creating a vehicle from scratch that could autonomously pickup golf balls while having a chance to win a competition. I hope this project can be a remarkable feat that me and my team can be very proud of. I am very excited for this project and will work my hardest and give everything I can to the team in order to achieve our goals.

Kevin Springer:

This project quickly got my attention due to my interest in machine design and designing mechanisms that will have a practical impact on the world. This project further interested me and even got me a bit excited due to the competition aspect. I'm fairly competitive by nature and enjoy playing games against other people, whether in person, online, digitally or otherwise. I always strive to be the best at what I do but also enjoy having fun while doing it. This project allows me to put my learned engineering skills to use while indulging in my competitive nature and having some degree of fun while we are at it. Previous projects I have worked on have all been either "dumb" in nature or purely conceptual. This project will be the first time I can work on something that will exist in the real world that is meant to intelligently move around rather than follow a predetermined, linear path. This project will also have a real world impact in that we are designing something that has the capability of reaching mass market production and use while existing in a somewhat unexplored field.

This project is also a capstone which will demonstrate to myself and my future employers that I have put my engineering skills I have learned to use. I sometimes struggle with self doubt and feel as if I had learned nothing aside from how to pass the classes presented to me by UCF. These doubts are often dissuaded when I compare what I know I know now to what I now know that which I did not know prior. This project provides me with the opportunity to put those doubts away for good and prove to myself that I am the engineer that my degree will indicate.

Sean Gallagher:

The opportunity to design and create a working robot is definitely an exciting idea. Now adding aspects such as being automated and collecting objects, make this project a real challenge. Taking on challenges and learning from them is something that I strive to do. This project will strengthen communication skills, enforce the knowledge gained from lectures, and encourage creativity. The goal of having a working robot at the end of senior design is going to push my time management abilities, but the desire to win will fuel my determination.

The best part is that I am not in it alone. Being part of a team gives me the ability to engage in creativity, help and motivate one another, and give/receive critique. I'm part of a team that is dedicated to quality work, which in it of itself is a major source of motivation. The lessons learned and the experience that we will gain over the course of this project may be worth more than all previous semesters combined and will, no doubt, help solidify the foundation for a great career.

Team Contract

1. All students are expected to treat each other with respect.
2. Should a student have a grievance with the way they are treated, such student is expected. to air this grievance with the team.
3. Should a student agree to a meeting time and fail to attend or arrive more than 15 minutes late without a valid excuse, such student will receive a strike.
4. Should a student agree to a deadline and miss such a deadline without a valid excuse, such student shall receive a strike.
5. Three out of the four students not in offense must agree that a strike is warranted for the strike to be recorded.
6. Should a student receive two strikes, such student is put on probation and a meeting is held with the advisor to discuss the situation.
7. Should a student receive three strikes, a team meeting is held regarding whether the offending student shall be expelled from the team.
    a. A unanimous vote of students not in question is required to expel a student from the team.
8. The accused student has a right to self defense at all relevant meetings where such voting occurs.
    a. Should the offending student miss the agreed upon time for a meeting, such student waives the right to self defense.
9. Professionalism is expected at meetings with the advisor and in meetings regarding strikes.
10. No meeting shall occur during class time.
    a. An exception occurs when such a class is not scheduled to occur.
11. Should a student participate in any offending behavior not outlined above, a unanimous vote of the other students may award a strike.

Main Goals and Objectives

The following are our must-have goals:

- Create a robotic device capable of transporting itself on grassy terrain.
- Program the device to move autonomously while avoiding obstacles.
- Completed device will be able to detect and collect a minimum of 24 golf balls.
- The device will be able to determine when collection is completed and return to the designated “home” area.
- After golf ball collection, the device will empty all golf balls in the “ home” area.

- The device will be able to navigate towards a golf ball autonomously within a certain distance of a golf ball.
- The device must be able to stay within bounds of the 75 feet by 75 feet boundary.
- The robot will be able to repeat tasks as necessary, maintaining its durability.
- Create and complete the project in a timely manner and within financial restrictions.
- Include a manual emergency off button.
- Leave the terrain unharmed.

Stretch Goals

The following are our nice-to-have goals:

- The device will be able to drop off collection of golf balls in any “flagged” area, not necessarily in “home” location.
- Be able to collect 60 golf balls.
- The device will be able to navigate towards a golf ball fully autonomously.
- The device will be able to handle image recognition and determine if there is a golf ball or drop off zone within view of it’s sensors/cameras.
- The device will be fitted with a pickup mechanism that will pick up golf balls quickly and efficiently.
- Our device will be faster than the other teams.
- The robot will be completely solar powered.
- Maintain an accurate count of golf balls collected either by detection or by weight of storage facility.
- The device will be able to send error messages to an external device for debugging purposes.
- Robot is able to detect its own malfunctions and as a result the device will shut down or return to “home” as necessary.
- The device will be marketable to consumers.

Constraints

The following are specific constraints for the competition day of our completed autonomous device:

- The competition course will be a 75-foot by 75-foot square of natural-surface grass.
- Past competitions have been conducted outside the UCF Bounce House on publicly accessible grass areas (non-athletic surfaces). The area will be cornered by standard Orange Traffic cones to identify the perimeter of the competition zone.

Grass height and ground contour are at the mercy of UCF Groundskeeping and thus are part of the competition challenge.

- Between 24 and 60 regulation golf balls will be scattered into the competition course by faculty or judges.
- Teams will have three rounds of 15 minutes each to collect the maximum number of golf balls. Winner will be determined by lowest time. In the case that no team finishes in under 15 minutes, the winner will be determined by the greatest number of balls collected.
- Teams can place anything <u>outside</u> the course perimeter they wish (visual guideposts, markers, humans, sensors, electronic devices, etc.) but may not place anything (or anyone) <u>inside</u> the perimeter. Electromagnetic, acoustic, or other non-contact intrusion into the field of play by devices or individuals outside the perimeter is acceptable.
- Teams will be expected to incorporate a payload-finding sensor mechanism (or mechanisms), as one goal is to maximize autonomy. It is anticipated that teams may desire some method of manual control, but that level of control is intended to be limited. Some <u>candidate</u> limitations might include:
    - The vehicle is prohibited from approaching within 30 inches of a ball targeted for collection under manual control. A vehicle may be manually remote-controlled towards the proximity, but "terminal guidance" over the last 30 inches must be autonomous. A vehicle may drive within 30 inches of a ball as long as that ball is not targeted for collection (essentially permitting a team to drive PAST a non-targeted ball).
    - Vehicles are intended to autonomously detect, engage, grapple/collect the payload without using manual control (this includes the collection mechanism).
    - Teams are prohibited from utilizing hobby style radio-based remote (manual) control for more than 30 seconds continuously. After each period of manual control, the system must not be controlled via manual control (a "time out" period) for 30 seconds. This ensures that teams that use manual control sparsely and utilize autonomous control extensively should face little or no interruption in active collection. Any other method of RF control other than Wi-Fi falls under these same constraints (Bluetooth transmission would be another example).
    - Teams who utilize a Wi-Fi-based connection for remote control from offsite (deemed 300 feet or more from the competition field) may have their manual-control duration extended to 90 seconds (followed by the required 30-second time-out). Anyone exerting such Wi-Fi-based control must not have line-of-sight of the vehicle.
- All balls collected must be returned to a 10 foot by 10 foot "drop zone" in one corner of the competition area (marked by standard duct tape on the day of competition). The vehicle can discharge collected balls manually or autonomously. <u>Only</u> balls that

have been collected and successfully discharged into the drop zone are considered "collected" for scoring purposes. Balls remaining inside the vehicle (regardless of vehicle location) are not considered collected.
- Vehicles must start within the Drop Zone at the start of the timing period. If a team is forced to send a human into the field of play to service their vehicle (or move it for any reason), the vehicle must be returned to its original starting position. Time will not stop during any portion of this human intervention.

Broader Impacts

Our project could benefit future technologies in the field of autonomous robots. At a minimum, our device could be used at golf courses to retrieve any remaining golf balls on the course. This could be helpful particularly if our device is capable of searching and detecting golf balls that are not easily seen with the human eye. Golfers will be amazed with this intelligent vehicle, but there are so many more purposes that our vehicle can impact.

Continuing forward, the design of an autonomous vehicle being able to detect an object, avoid obstacles, retrieve the object, and return home is highly desirable for other purposes. Our project could be adapted to create an automatic lawnmower, vacuum cleaner, and so much more. Some of these purposes may seem small but there are also larger impacts that our project will be able to stem to. There are many dangerous places in the world and it is much better to send an autonomous vehicle to retrieve a precious payload or even another human being. Some of these larger purposes may include a disaster search and rescue, mining for a specific, precious resource, retrieving volatile/harmful items, etc.

Furthermore, the main ideas behind our project such as object detection, collision avoidance and navigation could be applied to full sized autonomous vehicles. While necessary modifications would need to be made to abide by traffic laws, our technology would be capable of the basics required for transportation. There are already autonomous vehicles in production like the Tesla, but our visualization of our project will be able to impact broader aspects than just transportation. As a team, we hope that our final project design would be able to be utilized by the general public, and the United States Military. Autonomous vehicles just have a plethora of applications and we hope that our autonomous vehicle will be able to make a large impact in our community and our world.

Legal, Ethical, and Privacy Issues

Legal Issues

The following include several (not all) patents that relate to our project:

- 10782705 – Claim obstacle detection for robotic work tool system and beacon marker. Possible embodiments include vacuum cleaner, golf ball retriever robot, snow removal tool, leaves blower robot, floor cleaner, street sweeper, and farming equipment.
- 10646997 – Claim navigation for robotic working tool system using position determining device such as Global Navigation System. Possible embodiments include vacuum cleaner, golf ball retriever robot, snow removal tool, leaves blower robot, floor cleaner, street sweeper, and farming equipment.
- 10172282 – Claim plate spring to hold a tool for robotic working tool system. Possible embodiments include vacuum cleaner, golf ball retriever robot, snow removal tool, leaves blower robot, floor cleaner, street sweeper, and farming equipment.
- 10709939 – Claim device for retrieving golf balls in not easily accessible areas that are hard to reach. Comprising a retriever head attached to a telescoping handle.
- 10799770 – Claim radio frequency identification golf ball testing through use of sensors.

Ethical Issues

Whenever a device is autonomous, it raises many ethical questions. If a device is independent of human control how can it be guaranteed that it will not be harmful to others and the environment? Our design hopes to have zero negative impacts on the environment. Because of the nature of retrieving and collecting golf balls, it is unlikely to disrupt any animals or natural areas. It is more likely to have a positive impact in the situation of collecting a golf ball that may have otherwise been overlooked and left by a human. In the case that our robotic design happens to malfunction, we plan to implement an emergency stop button. This way we can shut down the device before it can possibly harm people or stray into undesired areas.

Furthermore, since Golf Ball Search and Rescue is a small scale version of an off road vehicle capable of rescuing and retrieving specified targets, we need to incorporate plenty of safety measures to ensure that the person/payload that we are rescuing will not be damaged in the process of the retrieval.

Continuing forward, another ethical issue that our team is aware of is discrimination. As a team, we will not discriminate against anyone of their race, gender,culture, etc. We will be sure to also design and create our autonomous vehicle in a way that it will be tasteful and as inoffensive as possible.

Privacy Issues

To use our golf ball collector, no personal information will be required nor gathered from the user. This eliminates any concern of data leaks. However, since our robotic vehicle intends to have a camera for golf ball detection, it raises the concern of privacy of any nearby people being captured on the live feed. Our footage could possibly capture private interactions of its surroundings. Due to the height of the vehicle, this will be unlikely, but to further prevent any privacy issues, the images captured will not be saved.

Overall, the design and purpose of our automated vehicle is not for violating anyone's privacy. Whether it being intentional or unintentional. Our competition location will also be in a controlled environment, which will be the University of Central Florida's football field. This means that there shouldn't be anyone in our competition area that is not a part of the University.

Specifications and Requirements

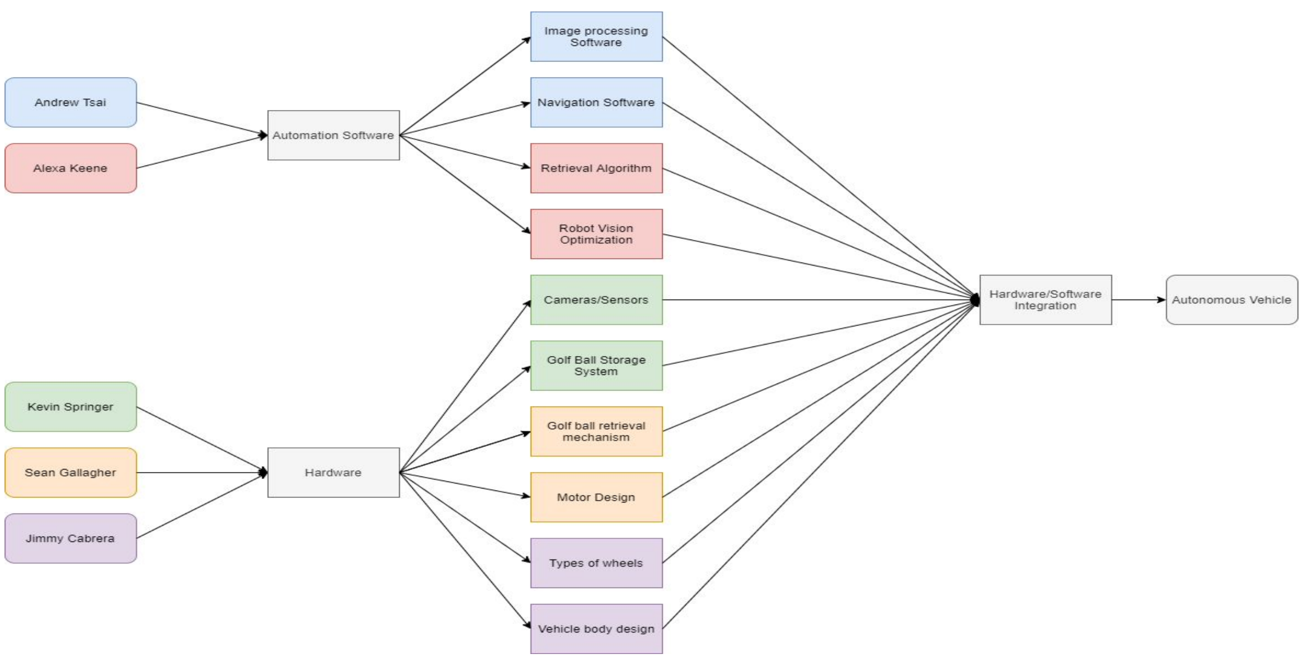
- Four-wheeled vehicle or treads
- Battery powered or solar powered
- Wheel sensors
- Front camera for golf ball detection and autonomous simulation
- Storage mechanism
- Golf ball pickup mechanism
- Designing an algorithm capable of picking up golf balls

List of Ideas

- Attach a rolling golf entrapment system to the front of the vehicle.
- Pick up golf balls using a vacuum.
- Create an arm to the front of the device that can scoop golf balls.
- Have a dump-truck style collection system that can lift upwards to empty golf balls.
- Use solar panels to power the device.
- Have a camera on the back in addition to the front for obstacle detection when moving in reverse.
- Use a backtracking algorithm to cover all of the designated area.
- Launch the golf balls at the drop off area as soon as collected to eliminate storage necessities.
- Multiple vehicles swarm the area for mass and rapid collection.
- Tricycle style with one front wheel controlling direction.
- Rotary style frame that sits on top of the wheels.

- Have orange cones surrounding the competition area for in-bounds detection.
- The ability to laser designate golf balls.
- Mini vehicle that will scan for golf balls. One searches, one collects.
- A sticky layer on the outside of the vehicle that will get golf balls stuck on it.
- Shoot and retract a suction cup for retrieval.
- Crane mechanism to pick up golf balls (claw).
- Manual golf ball removal from storage mechanism.
- Tentacles with suction cups that will pick up golf balls.
- Additional robot helper to remove golf balls from the main robot.
- Home docking station vacuums the golf balls out of the mobile robot.
- Trap door mechanism on the bottom of the storage tank to release golf balls.
- Use a trailer system to hold golf balls. Could have multiple trailers that can be hooked up and interchanged if the current trailer reaches capacity.
- Create an app for the autonomous vehicle
- Create a remote control to take manual control whenever necessary

Block Diagram



Decomposition Analysis

- **Functions**
  - Traverse Terrain
  - Understand Surroundings
  - Identify Golf Balls
  - Pick Up Golf Balls
  - Store Golf Balls
  - Count Golf Balls
  - Remove Storage
  - Respond to Commands
  - Autonomously Operate
  - Navigate Defined Space
  - Backtracking
  - Steer
  - Protect Golf Balls
  - Signal Outside World
  - Report Problems
  - Adapts to Environment
  - Able to be Lifted and Carried
  - Store Energy
  - Is Affordable
  - Is Marketable
  - Capable Field Repair
  - Is Reliable
  - Powers on/off
  - Easily Serviceable
  - Uses Commonly Available Parts
  - Takes Up Little Space
  - Easily Manufactured
  - Compliant With Law
  - Easy to Use
  - Withstand Environment
  - Is Durable
- **Components**
  - Main Structure
  - Ground/Vehicle Interface
  - Motor(s)
  - Power Transfer System
  - Acceleration System
  - Deceleration System
  - Directional Control System
  - Visual Intake System
  - Computer Interface
  - Golf Ball Grabber
  - Golf Ball Holder
  - Golf Ball Sensor
  - Distance Measurement System
  - Cargo Disposal System
  - Wireless Interface
  - Light System
  - Light Indicator System
  - Energy Storage Device
  - On/Off Switch
  - Boundary Sensor

Project Budget and Financing

We plan to spend 70% on hardware and 30% on software components.
Note: The prices are tentative

Lab Equipment	**Value Price**
Raspberry Pi Camera	$0.00
Arduino Board	$0.00

Subtotal value: $0.00

Purchase Equipment	**Price**	**Link**
LiDar	$119.00	https://www.amazon.com/youyeetoo-Slamtec-Scanning-Avoidance-Navigation/dp/B07VLFGT27/ref=sr_1_4?dchild=1&keywords=lidar&qid=1613877805&sr=8-4
Wheels	$14.99	https://www.amazon.com/Electric-Magnetic-Gearbox-Plastic-Yeeco/dp/B07DQGX369/ref=sr_1_3?dchild=1&keywords=robot+wheels&qid=1613877851&sr=8-3
Treads	$24.99	https://www.amazon.com/Robot-Crawler-Tank-Treads-Tracks/dp/B07HBSWR1D/ref=sr_1_2?dchild=1&keywords=robot+treads&qid=1613877912&sr=8-2
Solar Panels	$11.99	https://www.amazon.com/Sunnytech-250ma-Module-Polysilicon-Charger/dp/B00Z2XC3B4/ref=sr_1_5?dchild=1&keywords=robot+solar+panels&qid=1613877937&sr=8-5
Batteries	$60.72	https://www.amazon.com/iRobot-XLife-Extended-Battery-Accessories/dp/B07L46W8KB/ref=sr_1_10?dchild=1&keywords=robot+batteries&qid=1613877956&sr=8-10
Motor	$11.99	https://www.amazon.com/Antrader-Motor-Shaft-Arduino-Smart/dp/B07DDC3ZBK/ref=sr_1_2?dchild=1&keywords=robot+motor&qid=1613877987&sr=8-2

Framework	$24.99	https://www.amazon.com/Robot-Chassis-Motor-Arduino-Raspberry/dp/B07F759T89/ref=sr_1_7?dchild=1&keywords=robot+frame&qid=1613878023&sr=8-7
Storage Container	$19.90	https://www.amazon.com/Olive-Kids-Robot-Embroidered-Lunch/dp/B06XC4JBJB/ref=sr_1_5?dchild=1&keywords=robotic+storage+container&qid=1613878077&sr=8-5
Collection Mechanism	$64.99	https://www.amazon.com/Adeept-Robotic-Compatible-Programmable-Processing/dp/B087R8DLG6/ref=sr_1_2?dchild=1&keywords=arduino+robot+scooper&qid=1613878152&sr=8-2
Sensors	$7.99	https://www.amazon.com/HiLetgo-Infrared-Avoidance-Reflective-Photoelectric/dp/B07W97H2WS/ref=sr_1_3?crid=37YBDS95CCIX1&dchild=1&keywords=robot+sensor&qid=1613878180&sprefix=robot+sens%2Caps%2C175&sr=8-3

Total: $441.55
Project Value Total: $441.55

Project Milestones

Date	**CS Milestones**	**MAE Milestones**
February 10th, 2021	Bootcamp Team Formation	Team Contract
February 17th, 2021	Teaching Assistant Check-In I	
February 22nd, 2021	Initial Design Document, 15 pages	Technology Memos/Round 1 Research
March 1st, 2021	Round 1 Research Topics: -Retrieval Algorithms (A.K) -Navigation Software (A.T)	Round 2 Research Topics: -Power Transfer System (SG. -Ground Interface System (K.S) -Main Structure
March 8th, 2021	Project Status Presentation	
March 15th, 2021	Round 2 Research Topics: -Image Recognition (A.K) -Robot Vision Optimization (A.T)	Round 3 Research Topics -Ball Retrieval Devices -Sensors
March 22nd, 2021	Round 3 Research -Hardware Integration (A.T, A.K)	Round 4 Research Topics: Structural Analysis and Testing Procedures
March 29th, 2021	General Robot Design Visualized 15 Total Pages Each	
April 5th, 2021	Teaching Assistant Check-In II	
April 12th–16th, 2021	Spring Break	
April 19th, 2021	Finalize Robot Design	
April 28th, 2021	Final Design Document, 150 pages total 30 Total Pages Each	
May 5th–Aug. 20th, 2021	Summer Break	
December 6th, 2021	Final Project Due	

Research

Investigation into Motors and Motor Controllers

Building an autonomous ground-based vehicle capable of traversing terrain to collect small round objects, like golf balls, comes with many aspects and challenges. This memo serves to dive into a main aspect of the function and design of the vehicle, the motor and motor controller. As a required objective, the vehicle must move and although there are several ways to accomplish this task, certain assumptions must be made to narrow the research process. Likewise, to expand the depth of the research, decisions will be made to examine finer details of each component. The first decision that needs to be made is the type motor to 'drive' the vehicle. This allows for the question, electric power or combustion power?

Electric Motor v Internal Combustion Engine

While combustion engines have been around longer than electric motors, understanding the needs of the vehicle and comparing the two identifies a clear victor. The first thing compared is the most obvious, the 'fuel' type. Electric motors convert electrical energy to mechanical work with the help of magnets, while combustion engines use chemical energy (gas) to produce mechanical work. The energy stored in gas is about 40x higher than the energy that can be stored in a lithium-ion battery [1]. However, electric motors have about a 90% efficiency of converting that energy into motion while combustion engines are far less efficient [2]. Combustion engines are also more complex, "Electric engines on average may have something like 20 parts, whereas combustion engines may have more than 2,000." [3]. Although the construction and maintenance of the motor/engine is not a required objective, simplicity is desired due to the timeframe and learning curve of the project. Energy storage and safety are important factors as well. Since the energy storage of the fuel in combustion engines is so high, the fuel tank can be a lot smaller than a battery to provide the same amount of energy. However, gas is flammable and requires safety measures that will overshadow this benefit. Therefore, due to the safety, simplicity, efficiency that an electric motor provides, the below research will focus on it and its integration into the vehicle.

Types of Electric Motors

There is an extensive offering of electric motors, the most fundamental being alternating current (AC) and direct current (DC) motors. For the use of this project, the vehicle will be traveling around a perimeter in an outside location. Because of this, the need for energy storage is a main requirement. Since DC motors can be battery powered [4], the choice is clear. Even further, DC motors have better speed control, higher torque, and better acceleration [4]. But that's not the end of the tunnel. Brushed, brushless, servo, and stepper are a few types of DC motors each having their own advantages and disadvantages. Brushless motors are very efficient motors that have high life expectancy, but for budgetary reasons, will not be considered in this project. Brushed DC motors are more commonly used in moving robots because they have high torque and are simple to control [5]. Servo motors are much more accurate but can be complex. Steppers offer very accurate motion but produce less torque and are more complicated in application [5]. Since all three have some advantages, for the benefit of simplicity, we will narrow the research to brushed DC motors. Since a battery powered brushed DC motor would be a good choice, the range of motors now becomes dependent on the needs of the speed, torque, and voltage. DC motors come in a voltage range of 1.5V to 48V, but 6V, 12V and 24V are the most common [6]. Once specific requirements of load and speed are determined for the vehicle, the motor type can be narrow to a choice of manufacturer. Having the motor selected is great but is useless without a way to communicate/control it.

Motor Controllers

For DC motors, the speed at which they rotate depends on the voltage applied. Directly connecting a power source without any intermediate control devices would produce the maximum speed and could damage the motor. Having motor controllers is a must in order to have a precise and efficient moving vehicle. Furthermore, a main objective in this project is for the robot to be automated. This will add a layer of complexity that will be noted but not detailed in this section. Familiarity of Arduino inspired a look into their options of motor control. There are a couple of components needed for successful control. Pulse width modulation, PWM, is a way to provide the motor with a desired voltage by averaging bursts, or pulses, of voltage [7]. Regulating the speed and direction of the motor can be accomplished with two components, a L298N motor driver and an H bridge. The L298N has an H bridge integrated already into it which allows for a change in the direction of the motor by reversing the flow of current to the motor. It also is compatible with servo motors in addition to brushed motors due to offering a higher voltage capacity [7]. An advantage of the L298N is that it allows for the control of 2 DC motors. This will help our project with dynamic motor control and allow for similar integration of an automated component/software. The power supply can be connected to the L298N which connects to the motor and an Arduino board [7]. The Arduino board can receive motion control logic which, for this project, should come from sensors and feedback with little user input.

Conclusion

The movement and control of the movement of the vehicle is a major objective for the success of this project. Narrowing the vast options of power generation is the first step in finding the best choice that will fit specific needs and constraints. Electric power, and the electric motor, offer a broad range of control, efficiency, and safety. Comparing AC or DC motors, the DC motor was determined to be a better fit due to the portability and safety. The types of DC motors (brushed, brushless, servo, stepper) all have their own advantages and disadvantages. These can be weighed once finer details and specific needs for the vehicle are determined but due to simplicity in control, brushed motors were chosen to look further into. Familiarity with Arduino lends their controller options an easy hand in the implementation of this project. Then L298N can assist in speed and directional control and allows for high voltage input. The vast field of motors has been narrowed and it is the hope and intention of this memo to advance the design and encourage the success of this project.

Manufacturing

Manufacturing is a huge part of the engineering industry. Everything that is engineered has to be analyzed, designed, tested and then manufactured. When engineering a part or product the design team must take into account the steps needed to manufacture the product, the more time consuming or costly the manufacturing is, the more the product will cost to the developer meaning either less profits or higher prices which decreases the demand. In this project the team is tasked with designing and building an autonomous robot capable of detecting and collecting golf balls on a competition field, while having certain restrictions on how much human interaction can be involved with the vehicle.

There are various manufacturing methods and materials that can be used to build this vehicle. CNC machining, 3d printing, laser cutting, among many others are key methods that can help the success of this project. There are pros and cons to each method which will dictate what should be used on the project. Since there is not a high budget, we only need to manufacture one piece so we can use techniques that are not usually appropriate. What methods are used will be decided later on once we undergo extensive research and have a base of what the team wants the vehicle to look like. Shape, size, weight of electronic components are all things that will dictate what material and manufacturing technique is used.

CNC Machining

CNC machining or computer numerical control a manufacturing process in which mills and lathes are controlled by computer code to remove material at very precise tolerances. “It is a computerized manufacturing process in which pre-programmed software and code controls the movement of production equipment” as stated by Goodwin university [8]. CNC machining starts with a 3D Design, using popular software such as solidworks or fusion 360. Once you have a good design, the model goes into cam software which is “the use of software and computer-controlled machinery to automate a manufacturing process” [9]. In CAM the model is run through different steps which allow the user to set tools and paths when cutting the part, the user also has the ability to simulate the path the machine will take in order to avoid mistakes and failures which can result in damages to the machine, tooling and product. After the CAM portion is complete a G-code is generated which then tells the machine exactly what tool to use, where to cut and how fast. An example of G-code is G01 X1 Y1 F20 T01 S500 in which G01 is the type of move, X1 Y1 are the coordinates, F20 is the feed rate or the distance which the machine travels at one spindle revolution, T01 sets which tool to use and S500 is the spindle speed [9]. Once the G-code is generated the raw material is placed in the fixture (usually a vise) on the machine and the coordinates are set. Once everything is prepared, the G-code is fed to the machine and the part can be cut from the material. One of the many benefits of CNC machining is the quality of the parts, these parts are made to extremely tight tolerances which guarantee a quality lightweight product. The setback of using CNC machining is cost. The cost of using a CNC machine is on average $40 dollars an hour. The basic part can take up to two hours to make, add in the cost of the material and one small part can add up to $100 dollars.

3D Printing

Another relatively new process that can help on this project is 3D printing. 3D printing offers many benefits to lower budget consumers such as our team, with this technology you can create a part to test and prototype before making a final version on a CNC machine. It can also be used to create parts on the vehicle which are not subject to high stress, for example as a base for the circuit board. There are many types of 3D printing available which are Stereolithography (SLA), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), Digital Light Process (DLP), Multi Jet Fusion (MJF), PolyJet, Direct Metal Laser Sintering (DMLS) and Electron Beam Melting (EBM) [10]. For this project Stereolithography, which is the original form of 3D printing is appropriate, as opposed to CNC machining which is a form of subtractive manufacturing, SLA is additive manufacturing which means the object is created by adding filament in the end creating the part. “SLA parts have the highest resolution and accuracy, the sharpest details, and the smoothest surface finishes of all 3D printing technologies, but the main benefit of the stereolithography lies in its versatility” with SLA printing you can choose from a large variety of materials ranging from ABS to carbon infused plastic [11]. The most common material in 3D printing is PLA (Polylactic Acid), this material is low cost, easy to print, and very accurate. A major downside of PLA is that it's not very resistant to sunlight and heat, since this competition is set to be outdoors this material can become brittle and break with the heat meaning this might not be a good choice for this project. An appropriate material for sunlight and our application is ABS, it's readily available and very durable. ABS is "an ideal material to manufacture low-cost prototypes and architectural models for engineers or research departments" as previously stated this material can be used to model future parts created on a CNC or parts that do not require the strength and durability of aluminum or another alloy [12].

These two manufacturing processes can be huge assets to this team and facilitate the build of the vehicle. These two methods can be used to create key components. For example, we can use a CNC machine to create the chassis of the vehicle. This is the part that will be under the most stress. Another high stress part we should consider is the suspension or pieces that will hold the wheels or belts. 3D printing can be used to create parts such as a base for the electronic equipment or as bumpers in case the vehicle comes in contact with another surface. Not everything in this project has to be manufactured as we can always find existing parts that can help us move along in the build, such as using parts on other vehicles and adapt them to our project. As the project progresses the team will decide, based on the design, what are the appropriate methods of construction along with the correct materials to build an appropriate vehicle that can endure the competition as well as give us a chance to win.

Steering Mechanisms and Drive Systems

Steering Mechanism

Steering Mechanisms are sub-systems of components that allow systems to rotate, follow a particular course, or otherwise guide the system. While there are many methods of steering vehicles, methods such as rail switches and rudders will be excluded from this memo as they do not fall within the scope of this project. This section of this memo is outlined by various methods of steering ground based vehicles which fall within the scope of this project and provides a brief description of the history and function of each method, including the advantages and disadvantages of each.

The most conventional method of steering is to rotate the front wheels on an axis perpendicular to their axis of rotational motion. There are several methods to accomplish this. The first listed here is ackerman steering, which was developed prior to 1818 by George Lankensperger for use in horse drawn carriages [13]. It is defined by two equal length rockers connected by a coupler shorter than the ground. The ground bar is the axel connecting the two wheels. This arrangement allows the wheel on the inside of the turn to yaw more than the wheel on the outside. This arrangement allows all four wheels to rotate around a common center, avoiding the need for any wheel to slide sideways [13]. Prior to this development, both turning wheels operated on the same pivot, causing large disruptions from land geometry [13]. The disadvantage of this method of steering is the inability to directly operate the direction of the wheels. Since this system was intended for horse drawn carriages, it was directed by being pulled, typically by a horse. The utility that this system retains, however, is a method for allowing the vehicle to turn while avoiding lateral wheel slide. The system can be applied directly should we utilize the trailer approach I mentioned during brainstorming.

Still within the conventional method of steering is Bell-Crank steering, which is characterized by a sixbar linkage containing one central rocker connected to two wheel rockers via couplers [14]. The advantages of the bell-crank system include the degree of mechanical advantage associated with the design as well as the minimization of inputs on steering from the surface geometry [14]. Disadvantages of this system include complexity of the system as well as difficulty in maintaining proper precision in steering [15].

In continuing the conventional, the rack and pinion system of steering is defined by a central pinion translating a rack laterally as needed [16]. The rack is connected at either end by a coupler which is then connected to a rocker attached to the wheel. This method is one of the most commonly used methods in automobiles due to the limited number of parts required, the ability of the operator to feel the conditions of the road, ease of repair, and ability to vary steering ratio by varying the number of teeth per inch on the rack [17]. Disadvantages include less durability and increased vibrations [18].

Moving on to the less conventional, differential steering is a method in which more torque is applied to one side than the other [19]. This method is the predominant method of steering for treaded vehicles such as tanks or bulldozers, but is also used in some wheeled vehicles such as zero turn lawn mowers. It can also be used to augment steering in wheeled vehicles which use other more conventional means. This method of steering implies the necessity of applying different amounts of force to the wheels through the drive system. This can be accomplished either mechanically through differential gear systems with a single drive, or electronically with a motor for each side [20]. One advantage of this system is the ability to turn with zero turning radius. In other words, depending on surface conditions and the exact system the vehicle uses, a vehicle utilizing differential steering is capable of rotating in place without translating [19]. Other systems would require the vehicle to first move forward or backward in an arc in order to turn. Reversing the direction on one of the sides leads to an even faster rate of rotation. Drawbacks include the complexity of the potential differential gear set, and uneven terrain causing the vehicle to turn [19]. From my own experience with the mBot robot which utilizes a servo-based electronic differential steering, imperfections in the servos and the wheels can cause one side to continuously move faster than the other even when the computer indicates the sides to be the same speed. This causes the vehicle to continuously turn in a circle instead of a potentially straight desired path. The larger the discrepancy between the wheels, the tighter the circle the mBot would travel in. Without directly addressing the mechanical reason for this, the computer would need to compensate by indicating the slowed servo to rotate faster.

Drive System

There are several different ways to drive a vehicle to move. The first method of drive listed here is front wheel drive where the vehicle is driven forward by input motion provided to the wheels at the front of the vehicle. The front wheel drive system is as old as the automobile itself, dating back to the tail end of the 19th century [21]. The most widely used arrangement of a front wheel drive vehicle situates the engine and the transmission at the front of the vehicle mounted transversely [21]. The advantages of the front wheel drive system include simplicity, fuel efficiency, greater weight over the driving wheels which incurs greater traction, and an avoidance of loss of traction in the rear wheels when cornering [22]. Disadvantages include the phenomenon of torque steering and a reduction in lifespan of the front wheels as a result of the aforementioned increased weight above them [22]. Torque steering as a phenomenon was outlined above, wherein a vehicle is steered to one side or the other as a result of unequal power being transmitted to either side. The increased weight above the driving wheels, while an advantage in traction, is a disadvantage when it comes to lifespan because of the increased force and consequently increased stress felt by the wheels and the tires.

Opposite to the front wheel drive is the rear wheel drive. As the name implies, the force of the engine is applied to the rear wheels of the vehicle while the engine is most commonly arranged longitudinally at the front of the vehicle. Rear wheel drive got its start right alongside front wheel drive and was the dominant drive system of the 20th century [23]. The dominance of this system began to wane in the latter half of the century when the federal government instituted Corporate Average Fuel Efficiency standards. The advantages include increased acceleration, an avoidance of torque steer, and greater weight distribution while the drawbacks are lower fuel efficiency, less traction, the necessity of a drive shaft down the middle of the vehicle, and the complexity of a rear differential [22].

All wheel drive is a drive system where the drive is applied to all of the wheels on the vehicle. This system is specifically called four wheel drive when the vehicle only has four wheels. The system competed with the other two aforementioned drive systems at the dawn of automobiles but due to complexity was not practical until nearly a decade later [22]. The all wheel drive system brings about greater traction by driving every wheel against the ground and is therefore beneficial on off road terrain [22]. This system incurs increased weight and complexity and therefore less fuel efficiency [22].

An alternative to all of the above systems of drive is the direct drive system, wherein the electric motor applies force directly to the wheel rather than an axel that drives each of the wheels. This technology was first explored with the advent of the automobile, but due to the increasing advantages of the gasoline engine was soon abandoned [23]. This technology is often seen today in remote controlled cars as well as electric bicycles and motorcycles [25]. The advantages of this system include increased torque when starting from stop, decreased weight, brake steer, software differentials, brake bias, and an increased efficiency from lack drive train reducing the gears [25]. Disadvantages include and increase unsprung mass which in turn decreases stability [25].

Conclusion

By necessity, not everything outlined in this memo can or will be used in this project, though it does open doors to understanding why and how certain systems are used and allow for alternate paths to choose from. Considering relevant technologies, the roomba utilizes direct drive and differential steering [26]. This combination allows for a compact design and turning radius, two aspects which would be useful to this project.

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