Golf Ball Deflection System Project Proposal

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I. Introduction

Tennessee Technological University and DEVCOM have assigned us the task to design and construct an electronic automated system that can detect and intercept incoming projectiles. This project was given to two teams comprised of Senior Electrical and Mechanical engineers to compete against each other to create the best design based on very specific constraints and requirements [1]. The goal of this task is to create a design that can be taken to classrooms to increase interest in the Department of Defense for new STEM students. Due to this, our goal is to plan and construct a solution that both meets requirements and is as exciting as possible. We strongly believe that with the use of engineering knowledge and technology we can introduce and excite k-12 students in stem.

A. Outline

In this proposal, we have structured it with four major sections: Problem Analysis, Solutions, Broader Impacts, Project Feasibility, and Existing Solutions. Within the Problem Analysis section background knowledge, required specifications, constraints, standards, and expected difficulties are explained. In the background section, we explain important information that is known about similar systems. Under specifications and constraints sections we list the stakeholder's project requirements and technical shall statements to meet the constraints. Once the problem has been properly explained, we examine possible solutions, as well as measurables that are required to make them successful. In the broader impacts section, we discuss the future benefits and consequences that will occur after the completion of this project. Finally, in the project feasibility section, we list our team's strengths and weaknesses, expected budget, and timeline to complete this project.

II. Problem Analysis

The DEVCOM capstone team faces a variety of challenges when approaching golf ball interception. This includes tracking the projectiles, intercepting the projectiles, and communicating from the sensors to the interceptor. The team will address these problems within the bounds of the engineering standards and constraints set by the stakeholders.

A. Background

1) Tracking projectiles: The path that the projectiles take is guided by the arena layout [1]. The golf balls are tied to multiple fishing lines, which gives them a predetermined path to follow on as shown in Fig. 1. The fishing line is tied to 3 different anchor points as shown in Fig. 2. The golf balls will come from multiple directions and heights. There can also be multiple projectiles coming at once. The arena includes 3 pairs of sensor posts for tracking purposes. The sensors are needed to detect the position, speed, and acceleration of the projectile for the interceptor.

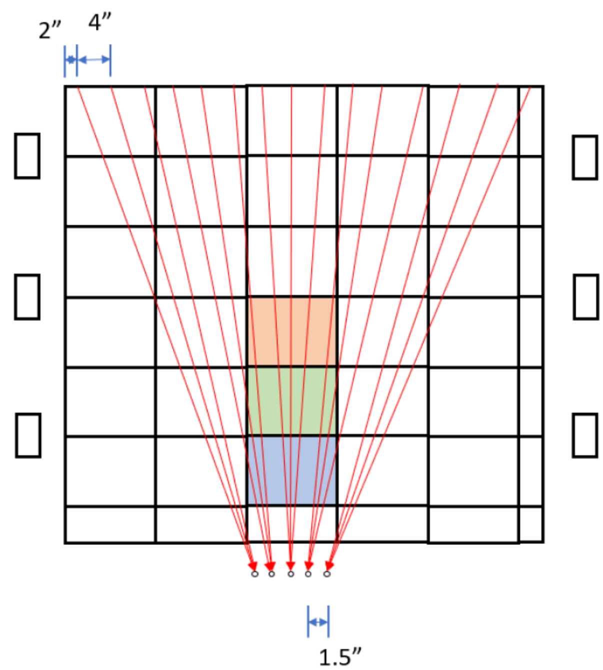

Fig. 1. Arial View of the Arena

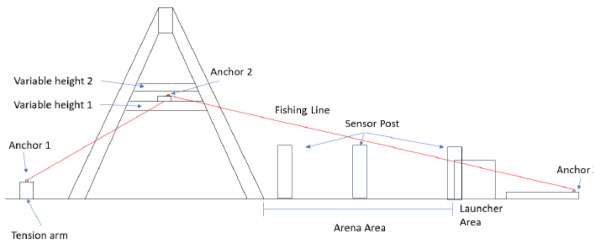

Fig. 2. Side View of the Arena

2) Intercepting Projectiles: The possible positions of the launcher are depicted by the red, green, and blue squares of the area shown in Fig. 3. The launcher must have the capability to shoot a projectile to influence the flight of the ball. The launcher's projectiles should not need to be reloaded by any outside human interaction and therefore, be fully autonomous during the start of the competition.

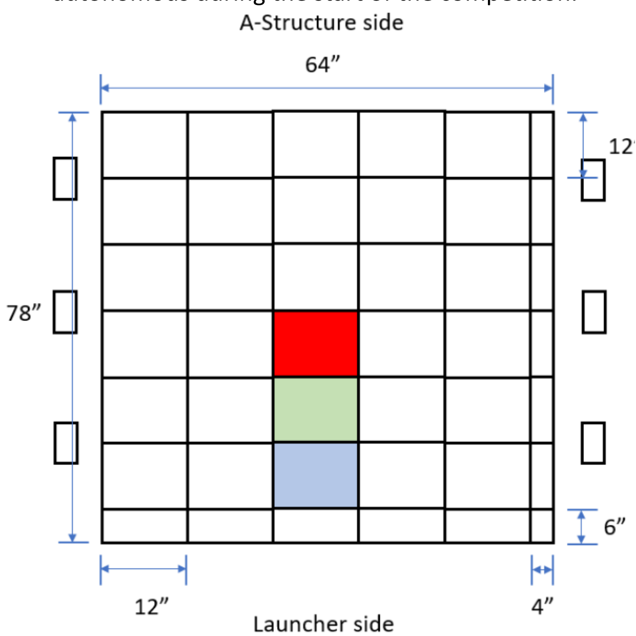

Fig. 3: Position of the Launcher relative to the Arena

3) Communication between sensors and launcher: The sensors cannot be wired directly to the launcher, meaning that there must be wireless communication between the sensors and launcher. The sensors must be powered by an internal power source, such as a battery. The transmission and processing of data from the sensor to the launcher apparatus must be done in a timely manner to intercept the golf ball before it is out of range of the launcher.

B. *Specifications*

The customer for the project, DEVCOM, provided a list of requirements for the device. Using the provided rules, a list of specifications has been created.

1) *Interceptor specifications:* The interceptor device must comply with the Interceptor Restrictions and Requirements section of the rules provided by DEVCOM [1]. As such, the powered-off interceptor must fit inside a box no larger than 1 foot in length, height, and width. The device will have a clearly labeled power switch as well as an emergency stop. It will be capable of communicating wirelessly with the sensor array and launching a projectile at incoming practice golf balls. Any projectiles launched will not pose a danger to observers. The device will be capable of operating autonomously after the initial setup with no input from external sources other than sensors. The interceptor will also comply with the safety requirements provided at the end of the rules document [1].
2) *Sensor specifications:* The competition allows the use of up to six sensor stands. The specifications of the sensor stands are listed in the provided rules [1]. Sensors will be able to easily mount to these stands and have minimal impact on the stability of each stand. Each sensor will be a self-contained unit containing its own power. Sensors will be able to wirelessly communicate with the interceptor device in order to relay the position of incoming projectiles.

C. *Constraints*

The following section states the objectives that must be accomplished by the team and outlines the scope of the project. These statements are used to ensure the project's success.

The team shall:

1) Create an interceptor capable of functioning on its own without outside interaction.
2) Create an interceptor capable of wirelessly communicating with the sensor array.
3) Create an interceptor capable of fitting inside a 1x1x1 foot box before powering on.
4) Create an interceptor that poses no danger to spectators.
5) Include a clearly marked power switch on the interceptor.
6) Include a clearly marked emergency stop option on the interceptor.
7) Design a sensor array that can detect approaching objects and relay their locations to the interceptor.
8) Design a sensor array that operates on battery power.

9) Design an interceptor that complies with the safety check list provided in the competition rules [1].
10) Design an interceptor that has lights.
11) Design an interceptor with decorations contributing to camouflaging of the device.
12) Design an interceptor which plays an alert noise before firing.

D. Standards

In this section, the standards that will govern or affect the design of the Interceptor will be stated along with background pertaining to the standard.

IEEE Code of Ethics: This standard dictates how engineers should coincide together in a work environment. Following this standard will allow the team to work together in a professional manner. [2]

IEEE 802.11: This set of standards applies when using Wi-Fi as the method of wireless communication from the sensors in the competition field. This standard regulates the frequency of the radio band the data is transmitted by, as well as the speed of the data transfer rate. [3]

FCC Parts 15 and 18: These standards constrain the radiated emission limits of certain electronic devices (based on their operational frequency) to ensure that the electronics used in a project will not interfere with the other electronic devices around them. [4]

IPC J-STD: This standard will be applied when soldering connections during the construction phase of the project. This standard helps regulate high performance soldered connections and list the methods and materials used when soldering. [5]

NEC 310.15(B)(16): This standard table shows the ampacity limits of a wire based on the gauge and material of the wire, as well as the temperature rating of the conductor material. This standard will aid the team when deciding which wiring will be needed for the project during the design phase. [6]

NFPA 79-10: This standard sets the regulations for the color and shape of the emergency stop button and will aid the team in designing this feature of the Interceptor. [7]

ISO 8573: This standard identifies the type of contaminants found in compressed air. Also, this standard separate different air quality levels into 9 classes. This information will be helpful to guide the team to make informed decisions about compressed air during the design process. [8]

IEC 60529: This standard regulates the protection of electrical equipment and will be helpful to the team when designing the housing, or enclosure, for the interceptor. [9]

E. Difficulties/Challenges

In the project's scope, there are some challenges the team will face. The first challenge is with the limited amount time the team will have to research, develop, and test the functionality of the Interceptor before the DEVCOM competition. Much of the hardware implementation will require multiple team members conducting research to further their knowledge to be able to efficiently design the entire Interceptor system as needed, as well as to perform well in the competition. This leads us into our next foreseeable challenge, which is staying within the constraints listed in the rule book for the competition, which were mentioned in the *Constraints* section above.

There will also be difficulties in several subsystems during the design phase. One of these difficulties will be detecting the incoming projectile, while also being able to obtain the necessary information from the projectile's flight path for our Interceptor to be able to make a direct hit to the projectile. Another challenge the team will face, will be ensuring the wireless data transfer from the sensors to the Interceptor's launching module can be completed within the budget, while also giving the launch module ample time to launch an object towards the incoming projectile with accuracy.

F. Existing Solutions

Other solutions for projectile interception can be observed in missile interception systems. There are multiple systems, but most rely on an array of sensors at different locations to provide real time location, trajectory, and velocity information. The data from these systems is uploaded to a base station that sends one or more counter projectiles to intercept the missile.

The most popular system is the "Iron Dome Missile Defense," and it was made popular due to its effectiveness in protecting Israel. This system works by detecting the missile using many radar sensors to track incoming missiles and send rockets to intercept them [10]. The drawback to this system is the cost and number of sensors required to make it effectively work. This project's design specification prohibits the use of more than 8 poles of sensors, and the radar cross section of a golf ball is very small, which would make radar likely unfeasible.

A system that is currently in development and may be able to be scaled for this project is called, "Iron Beam." This system works by focusing high power lasers to neutralize a target [11]. This is likely infeasible for a model, but this method could be modified to act as a target detector. By recording the reflected laser beam from the target, its position and distance can be determined. This modified system is an improvement because it requires significantly fewer sensors, as most of the detection takes place at a base station.

G. Summary of the Problem

What the team envisions to accomplish is guided by the shall statements listed above. The three main problems are as follows: tracking moving projectiles, intercepting moving projectiles and communicating from sensors to interceptor. These problems will present their own difficulties and challenges, such as detecting the necessary information to intercept a projectile. Further research into existing solutions for these problems, such as the proper sensor array for tracking projectiles, will ensure success for the team. These problems will also need to meet the specifications and standards required by the customer. All of these factors will be taken into consideration when coming up with a solution.

III. Solutions

A. Critical Unknowns

A main critical unknown is how well the target can be picked up by physical sensors. It is difficult to confirm how well distance sensors can detect an object that is the size of a golf ball. Another unknown is what methods of interception will be allowed by our customers. It is up for debate on whether the interception must include a projectile.

Although the customer offers guidelines on what is and is not an acceptable projectile, there are still safety and environmental concerns that must be addressed. If a physical projectile that is too small to retrieve (e.g. a plastic BB) is used, it may get lost and disturb the venue. Although projectiles must be nonmetallic and low energy – the system must be analyzed to ensure that these energy restrictions have no chance of being exceeded, which would pose a safety hazard.

B. Survey of Possible Solutions

1)Sensor Possible Solutions

One sensor solution is an optimized LIDAR sensor. This sensor would only require a single centralized sensor to determine the target's position and distance. This would act like the operating principle of a "spin-scan" laser imaging system [12]. An IR laser and IR receiver would be on a moving apparatus that scans the projectile field by angling the IR laser and measuring the reflection intensity. A peak of reflected light will tell the base station the target's position by recording the laser's pitch and yaw. Once this is known, the sensor should send pulses, and the time difference between transmission and receiving will determine the target's distance.

Another sensor solution is the use of multiple gates of IR beams with angled ultrasonic sensors. Once the target has passed two of the IR beams, the velocity will be known. The angled ultrasonic sensors will allow the base station to estimate the target's height and position left-to-right. This is repeated throughout the test field to determine the target's trajectory.

Another sensor solution is image recognition. One or more cameras will be facing the test field, with their video feed being transmitted to a computer. The computer will be running image recognition software, like OpenCV, to programmatically tell the system the target's position and trajectory. If multiple cameras are used either multiple computers will be needed, or the video feed would need to be wirelessly transmitted to a base station. A big concern about this method is processing time. For reference a research article concluded it took about 3.5 seconds for a Raspberry Pi to recognize a macaw in a still image [13].

2)Interceptor Possible Solutions

A) Possible projectiles: There are many objects that could be used to intercept and deflect incoming objects. One possible solution is foam bullets. Using a name brand product like "Nerf" they have darts with weights ranging from 0.84 – 1.08 grams and 2.68 – 2.89 inches [14]. This shows the wide variety of foam bullets that can be used to fit our needs. These would pass all Interceptor safety checklist items [1] with little altering required. Another projectile option is table tennis balls. According to USATT, a standard ball must weigh 2.7g and have a diameter of 40mm [15]. The spherical shape we believe would help the loading system design. However, due to the lack of density of a table tennis ball, it is expected that accuracy will be worse than alternative options. A third option for intercepting projectiles is a pressurized water stream. The benefit of using this method is instead of a singular object deflecting a projectile there is a constant stream, which will result in a larger surface area. However, with this solution the launching mechanism must use air compression rather than springs. Another material that can be used as a projectile is 3D printed design with a material like PLA. The use of this material has the benefit of having customizable density and area for increased accuracy and precision of our interceptor. However, with this solution will require additional time for testing to create the most ideal model and material. Finally, an addition to these projectiles could be to attach a tether to limit the flight to meet the safety requirements [1].

b) Possible Launching mechanisms: In order to accurately launch projectiles, we require a system that can produce an accurate and precise amount of energy per shot. The first launch solution is compressed air. A compressed air tank with the addition of an air pressure regulator can adjust the pound per square inch (PSI) to have the required launch velocity. One possible negative to this solution is the required space for an air tank. Another launch solution is a spring powered launching system. The power of this launching mechanism can also be adjusted by changing the tension of the spring. A possible negative for springs is they would have to be reloaded after every launch. This requires additional time between shots. Also, a separate mechanism would be required to reload the springs. Finally, another launch mechanism would be the use of rubber bands that are loaded with gears. This has the advantage of cost, because the cost for the materials is very small compared to other options. However, rubber bands will likely be less consistent power compared to Compressed air or springs.

c) Alternative Solutions: An alternative solution to the assigned task is to construct a robotic arm that can hold an object and swing at incoming projectiles. However, with the construction of the "Game Board" [1] it might not be possible to swing at the projectiles without destroying the board, and as stated by DEVCOM sponsor that would result in disqualification. On the other hand, if projectiles could be hit without destroying the board it would mean no projectile storage and reloading would be required.

B. Measures of Success

The listed measures below fulfill the requirement of the corresponding constraint above. Each measure fulfills only its corresponding constraint.

1) The interceptor will function on its own after initial startup. Beyond the initial set up of the interceptor and a reload, if the competition is tied the interceptor will function autonomously.
2) The interceptor will wirelessly communicate with the sensor array.
3) The interceptor will fit inside a 1x1x1 foot box before powering on. However, the interceptor may occupy more space after startup.
4) The interceptor and any projectiles it fires will pose no danger to spectators.
5) The interceptor will have a clearly marked power switch. This switch causes the interceptor to power on and begin operating when flipped.
6) The interceptor will have a clearly marked emergency stop button. The emergency stop button will be easily accessible on the exterior of the interceptor. The button will cause the interceptor to pause all operations for trouble shooting.
7) The sensor array will be capable of detecting incoming objects. The array will be able to determine the location, speed and trajectory of incoming projectiles in an efficient and timely manner.
8) The sensor array will be able to operate without wall power. Each unit will have an internal power supply included in the design.
9) The interceptor will comply with the safety requirements in the competition rules [1]. As such the interceptor will: have a power switch, have an emergency shut off, not use explosives, not use pyrotechnics, not make use of toxic or corrosive materials, not produce flame, the projectile will not be made of metal, the projectile will not break a piece of 8x11 paper two feet away, not shoot further than six feet, not rotate past 180 degrees, and the projectile will not be made of glass.
10) The interceptor will have lights included in the design.
11) The interceptor will have decorations which contribute to the camouflage of the device. These decorations will not hinder the effectiveness of the interceptor in any way.
12) The interceptor will play an alert sound before firing a projectile. This alert will serve to notify spectators before the interceptor fires.

IV. Broader Impacts

The golf ball interceptor will provide the necessary feedback for DEVCOM to evaluate if the current format of the competition is feasible and determine if it to be performed on a broader scale for schools across the nation. This will allow for a more streamlined experience for the future participants in the competition.

Another impact of the project is that it will encourage future students to learn more about missile defense and help explore new ideas on how to track and intercept projectiles.

As electrical and computer engineers, the team has a duty to follow the IEEE Code of Ethics. This includes the safety and welfare of the public. Therefore, the golf ball interceptor must not harm any bystander in the competition. The team should also abide by the rules of the competition that are stated in the rule book. The team should also present independent, original work and must cite any ideas derived from competitors in the competition.

V. Project Feasibility

A. Personnel and Skill Sets

In order to successfully create a Golf Ball Interceptor a wide variety of skills will be needed throughout the team. Skills in power, sensors, wireless communication, and motor control will be required. Each team member has basic skills in coding and circuit analysis. As the project progresses and more specialized parts are designed each team member's specialized skills will be required to incorporate these parts into the successful design. The team's individual skills vary and overlap very well with a general understanding of all aspects of this project and will be needed for integration of all parts.

- Adam Morrow
  - AutoCAD
  - Embedded Systems
  - Microcontrollers
- Allen Watson
  - LT Spice
  - PLC Programming
  - Power
- Colby Drake
  - Microcontrollers
  - Python
  - Power System Analysis
- Jonah Burke
  - PSS/E
  - Python
  - Power System Load Flow Analysis
- Tyler Kasuboski
  - Digital Logic
  - Power
  - VHDL

B. Necessary Software

There is a wide variety of software needed for the success of this project including three-dimensional design and printed circuit board design. The software that has been identified are: KiCad, AutoCAD, Arduino IDE, Visual Studio Code, Open CV, Raspberry pi OS.

KiCad is a cross platform and open-source electronic design automation suite [16]. This software will be needed when designing the wireless sensors that will detect incoming projectiles. AutoCAD is a computer aided design software that is used for 2D and 3D modeling [17]. This software will be necessary when designing the housing a launching mechanism for the interceptor as it has precise dimension restraints. Arduino IDE is an open-source Arduino software that gives ease flashing written code to Arduino boards [18]. This software will be used for programming and setup of the wireless sensors needed for the team's design. Visual Studio Code is a code editing software that has built in GitHub support, run, and debug features, and extensions [19]. Visual studio code will be one of the most used software's for the team as there will be many different aspects of the design that will need customized code to work properly with other systems. Open CV is a coding library used in computer vison [20]. Raspberry pi OS is the officially supported operating system for any raspberry pi [21].

C. Budget and Timeline

Because the device cost will be used in the team's scoring metric, the budget will be crucial to the success of the project and in competition. As a team we have formed many different ideas on how we can accomplish the goal of having a successful golf ball interceptor. Through the many different ideas, there is one main difference between the teams' ideas and that is how to launch the interceptor. The first budget is for a mechanical launching mechanism this budget can been seen from Table 1 in the appendix. The second budget will be for making a launching mechanism that uses compressed air to accomplish the goal this budget will be seen in **Error! Reference source not found.** in the appendix.

The team's timeline for this project will be approximately 11 months to completion. The schedule will align with the due dates for project sections. Most of the team's work will need to be completed in parallel for all subsystems to complete the project by the December 2024 deadline. A tentative schedule for outlining planning, design, system testing, integration, full system testing, and delivery of device is shown in Fig. 4.

VI. Conclusion

Autonomous projectile detection, accurate path and interception are the primary goals of The DEVCOM competition Golf Ball Interceptor. By using wireless sensors to detect the path of the incoming Golf ball and cameras to accurately fire an intercepting projectile to stop or remove the incoming Golf Balls momentum to prevent impacts to the golf balls target. The Golf ball interceptor will pave the way for future students' ideas and improvements to the design presented by the team in this document.

VII. Works Cited

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VIII. Appendix

Table 1: Mechanically Driven Interceptor

Part	Cost	Amount	Total
12V Power Supply	15.5	1	15.5
1KG PLA	19.99	1	19.99
Aluminum	29.98	2	59.96
Arduino ESP8266(5 Pack)	14.99	2	29.98
Battery housing	5.99	5	29.95
Bearings (10)	15.99	1	15.99
Cyllinder	12	1	12
Dart 1	18.99	1	18.99
Dart 2	7.99	1	7.99
Gears	20	1	20
HC-SR04	2.74	8	21.92
IR Laser	18.61	1	18.61
IR Reciver	1.09	1	1.09
Motor (Gears)	32	1	32
Piston	9	1	9
Piston Head	10	1	10
Rasberry Pi Camera	35	1	35
Rasbery Pi 5	79.99	1	79.99
Rubberbands	16	1	16
Servo Motor	13.49	1	13.49
Stepper Motor	14	3	42
30% Overhead			152.835
Total			662.285

Table 2: Compressed Air Interceptor

Part	Cost	Amount	Total
12V Power Supply	15.5	1	15.5
1KG PLA	19.99	1	19.99
Air pump	44.1	1	44.1
Air Regulator	124.98	1	124.98
Air Tanks	58	1	58
Aluminum	29.98	3	89.94
Arduino ESP8266 (5 Pack)	14.99	2	29.98
Battery housing	5.99	1	5.99
Dart 1	18.99	1	18.99
Dart 2	7.99	1	7.99
HC-SR04	2.74	8	21.92
IR Laser	18.61	1	18.61
IR Reciver	1.09	1	1.09
Rasberry Pi Camera	35	1	35
Rasbery Pi 5	79.99	1	79.99
Servo Motor	13.49	1	13.49
Stepper Motor	14	3	42
30% Overhead			188.268
Total			815.828

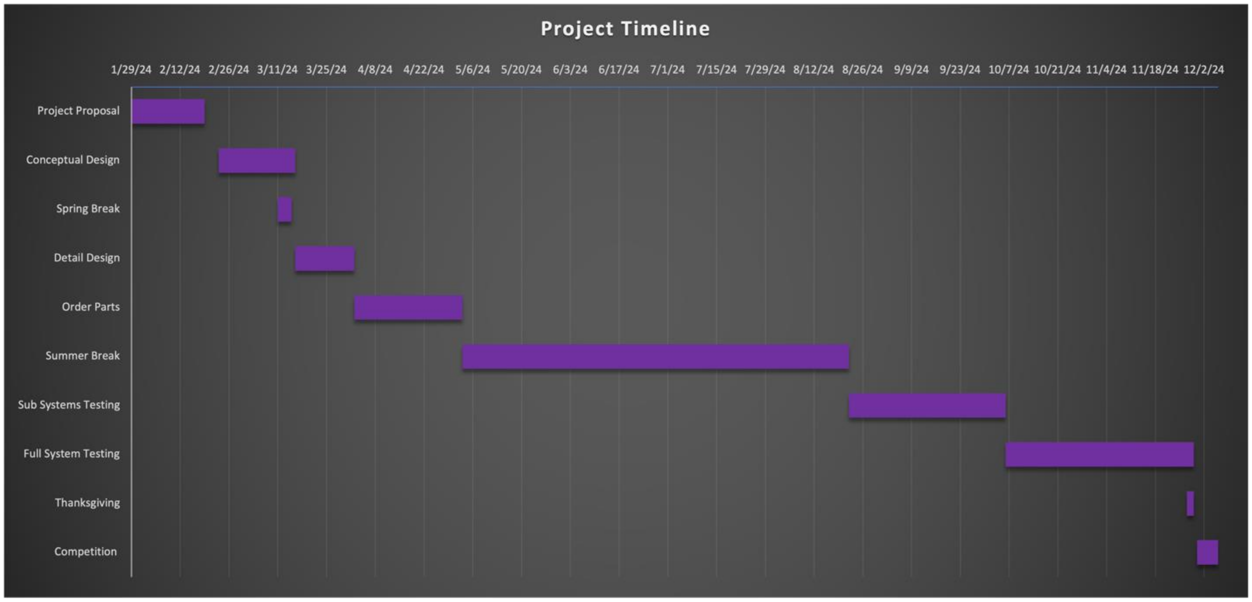

Fig. 4: Project Timeline