Paper Wad Interceptor Conceptual Design Final

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I. Introduction

This project's purpose is to design a paper wad interceptor, that will accurately detect and then deflect any incoming golf balls used to simulate paper wads for the design competition. This document will include all details associated with this system's conceptual design and how the specifications and constraints impact the design requirements.

The conceptual design is expected to give a broad overview of the goals for this project and provide the stakeholders and customers with several details for the general implementation of this project. The conceptual design fits into the engineering design process by being the initial design for this project to provide a high-level idea of the system and sub-systems while also setting the various expectations for the broader design. This document contains a brief overview of the problem including the fully formulated shall statements, the different subsystems decomposed from the original high-level design, different constraints that will impact the design of this project, and how this project's final design is intended to function. This broad understanding of what will be implemented in the project and how the constraints influence the possibilities of the different systems before deciding the details of the design is important in the development of the project as the team takes the next steps for designing this system.

A. Problem Statement

The paper wad interceptor's final goal is to deflect paper wads in the classroom by launching a safe projectile at the paper wad. However, this is a large project that would be very complicated to implement with the time given, so for the team's project's purposes the problem and objective have been scaled down and presented as a competition between two teams. The paper wad interceptor's role for this competition is: determining the height and exact wire the paper wad is incoming from, determining the speed of the incoming paper wad and the acceleration, firing the projectile on time and accurately so it will contact the paper wad, connecting each subsystem together while properly providing powering to the necessary subsystem's devices, and implementing a pause switch to stop and start the interceptor between rounds. This device must accomplish every task except the pause switch with no interference or input from any member of the team.

The only specified task the system must perform is being able to detect and fire at the incoming golf ball. This task is rather large and requires several requirements to be implemented properly. These requirements must be accomplished within the area of the gameboard with the interceptor placed in one of the three designated areas using the six sensor posts located around the gameboard. There are also optional tasks the interceptor can perform which include playing a noise when firing, having a light go off when firing, and decorations. These tasks offer additional points towards the competition. Both tasks shall be accomplished using the specifications and constraints outlined in the shall statements.

The first requirement for accomplishing this task is to determine the location and speed of the golf ball. Sensors will be set up on the initial sensor post, closest to the start, and will accurately determine which of the two variable heights the paper wad is, and the exact wire of the 15 possible the paper wad is travelling from. This will allow the firing machine to correctly aim towards the correct area to contact the paper wad as early as possible. For speed, early sensor stands will be used to get multiple speeds and possibly determine the acceleration. This will be done before a certain area to allow the interceptor to fire the projectile at the correct time and location to deflect the golf ball.

The next necessary action is designing the firing machine to fire the projectile on time to contact the paper wad. Using the data collected from the sensors, the firing device will accurately fire the projectile in compliance with the specified restrictions of force and distance of the projectile, while also deflecting the paper wad. The device will aim at the correct fishing line and at the correct angle to contact the paper wad every time.

The next goal of the design is to connect the sensors to the firing machine wirelessly and to power each subsystem of this project independently. The sensors should be able to rely any information quickly and accurately to the interceptor consistently so the device can properly intercept the incoming golf ball for every round. Each sensor will need to be powered independently with the correct voltage rating. In contrast to this, the interceptor itself will be powered by a wall outlet.

The final requirement for this project to function correctly is to have a physically connected pause switch to put the interceptor in an idle or active state. This switch will be controlled by a pre-determined member of the team and will put the device in a suspended state where it will never fire. This will allow the competition's judges to change the wire by which the paper wad is travelling or its height. Additionally, a power switch needs to be implemented to originally power up the device and turn the device completely off once the competition has ended. An emergency stop button will also be implemented to quickly shut down and de-energize the interceptor.

B. Shall Statements

1) The interceptor shall fit in a one-foot square on the floor and be able to fit in a one-by one-by-one foot box.

2) The intercepting device shall be designed to hold the projectiles and the launching mechanism components in this one-foot area.

3) This device will include an easily accessible exterior emergency shut-off switch to de-energize the system.

4) It shall also have a pause switch on the exterior of the interceptor that enters or exits a pause state for the system when flipped. This pause switch is implemented for any type of error with the gameboard or incoming golf ball.

5) The emergency shut-off is implemented in the event of a malfunction of the intercepting device.

6) The intercepting device shall have a power switch to start the system.

7) This device shall be plugged into the wall and be able to operate at a voltage of 120.

8) This device shall not rotate beyond 180 degrees.

9) The interceptor shall not alter or damage the gameboard in any capacity.

10) The projectile shall be allowed to hit the fishing line the golf ball is on but cannot break the fishing line.

11) The projectiles launched by the interceptor shall not make use of explosives, pyrotechnics, toxic or corrosive materials, and anything that causes flames.

12) The projectiles shall not be made of glass or metal of any kind.

13) The projectile shall not be launched past six feet.

14) It shall not be launched with enough force to penetrate an eight by eleven piece of paper from two feet.

15) The projectile shall be launched based on data received from sensors placed throughout the arena.

16) The connection between the interceptor and sensors shall be a wireless connection. This connection shall operate within the appropriate frequency ranges to meet federal requirements for free, unlicensed use. This will ensure the systems operates within the proper channel for free, unlicensed use.

17) The wireless connection shall be protected and secured to maintain the integrity of the intercepting system.

18) The sensors shall have stand-alone power that is not provided from a wall plug or any other wired connection.

19) The sensors shall be mounted on one of the six provided sensor stands or mounted on a device connected to these stands.

20) The team shall not have any member touch any part of the system once every part is set up and power is provided to the interceptor.

21) The team shall implement a warning label to mitigate children's attempts to imitate or recreate the intercepting system. This will avoid indirect harm to the children.

22) The team shall consider the most environmentally friendly options when choosing components to build the system. This will reduce the environmental impact of the intercepting system.

II. CONSTRAINTS

A. Standards

This project will require the use of wireless communication between the sensors and the interceptor. The necessity of wireless communication means that the federal standards regulating this type of communication. The team will adhere to the FCC 15.247 standard which outlines the frequency for Bluetooth and Wi-fi connections. To comply with this standard, the team will operate within the 2.4 GHz range or consider the 5 GHz range if Wi-fi is used to form the wireless connection. This standard also restricts the protocols and bandwidth restrictions that the team will consider when designing the communication system and other systems that rely on the speed of data transmission [1 & 2]. The requirements of this standard will determine the equipment needed to operate within these standards and how to design these systems to stay within the defined maximum speeds and protocols.

This device will also need to implement two different types of power systems. The interceptor device will be wall powered which requires either 250 volts for single phase devices or 480 volts for multi-phase devices according to the IEC 60335-1. Since this is an international standard, the interceptor must be able to function within these voltage limitations [3]. Typical wall plugs outside of industrial, or laboratory environments are also single phase. On top of that, wall plugs in the U.S. only offer 120 of these 250 volts for a single phase [4]. Thus, 120 volts should be used as the restricting factor unless a multi-phase connection can be provided by some means. With battery powered sensors, the sensor should have a voltage rating and a battery should be chosen accordingly.

B. Ethical

When simulating a defense system, there comes the concern that surrounding individuals may become influenced by the design or possibly try to imitate it. This is especially true around children where the impressibility in people is highest. With this system possibly being implemented into classrooms, this possibility is even more possible and should be accounted for in the system's design. To combat this the system will be accompanied by a warning label to help mitigate the potential for replications. This label will show individuals the harmful effects that imitating our design can have on themselves or their surrounding environment. At this stage in the design process, it becomes hard to design any other precautions. However, in the future if this design is implemented into classrooms, one solution could be a training seminar on the importance of not imitating the design that is placed in the classroom. This will show the students that it can be very dangerous if they do attempt to copy it.

Another ethical concern with this project is the use of wireless connection between the different sub systems. These connections could be Bluetooth or some type of Wi-fi, and each pose privacy concerns. It could be possible for some outside source to access the system's connection for whatever purpose. To combat this issue, the design will either determine a more secure option for its wireless connection or implement a type of privacy system with Bluetooth or Wi-fi like password protection. By doing this the project can effectively eliminate the risk of having its connections accessed by sources not connected to its own.

The project will also need to account for its surroundings when designing the firing mechanism and firing projectile. This is already being considered in the actual rules associated with this project, as the projectile cannot go further than six feet and cannot break through a piece of paper two feet away. This design will adhere to this rule as it is imperative that no surrounding entity be harmed or damaged by this project.

This project will maintain safety and ethical standards as the highest motivator while it is being designed. Making a functional and effective design is obviously the end goal, but it is imperative that any individual or entity involved not be harmed by this project in any way. This system will only function in a manner that cannot harm anything or anyone.

C. Broader Impact

The goal of this project is to defend the device from incoming golf balls. By doing so the launcher needs to detect the incoming golf ball, calculate its speed and position, rotate, and pivot the firing mechanism, fire, and intercept the golf ball before it reaches the launcher. There are many different subsystems that go into making the device function properly and implementing them together may cause problems. There are many components that the team will need to do research on. One of these components falls in the communication block that may be implemented using either a Bluetooth or a Wi-fi connection. Though standards and guidelines are being followed, a problem may arise where the sensors and the wireless connection may have issues. If proper communication is not accomplished the speed or position of the golf ball may not be detected making the system useless.

Not only does the team face the challenges of creating a design that works the team also faces struggles because this is the first year of the competition. Because this is the first implementation of the competition, rule-book changes, which have already affected the initial proposal phase, may continue to happen. However, as the project progresses more issues and questions regarding the rules will arise. Not only is the rule-book a possible issue but the team is not sure if the current set of restrictions will be possible. For example, a constraint was placed on the speed of the projectile being fired. The projectile must not break a piece of paper from two feet while also not going over a total of six feet. The mechanical portion of the team has raised concerns that this constraint may not even be possible. If they conclude that it is not feasible, another change to the rules may occur.

Another issue that needs consideration is the overall impact the design may have on the environment. The team will make an attempt to ensure that no toxins or harmful materials are being exposed to the environment and more eco-friendly options are chosen when necessary. To minimize our economical footprint, the team plans on using components that can be easily recycled. This may mean that the components can possibly be recycled in other capstone projects. The team will also use computer testing where applicable to minimize destroying any components to reduce unnecessary purchases which will minimize waste. Decisions will be made with these ideas in mind.

III. Block Diagram and System Overview

This project can be split up into eight main, interconnected subsystems: mechanical, device power, battery power, wireless communication, processor, sensor, and emergency stop and pause. There is also another small subsystem consisting of extra devices that are not necessary but beneficial to the competition portion of the project. These subsystems should work in unison with each other such that the entire system is able to detect the incoming paper wad and shoot it with a projectile before it reaches the end of the fishing line. The sensor subsystem takes the highest priority because all other subsystems are dependent on the data it collects.

A. Mechanical

The mechanical subsystem, outlined in orange in the block diagram, should be able to maneuver electric motors mounted on the launching mechanism to precisely aim at the incoming target within the "kill zone" and shoot a projectile. There are three data inputs (aim, load, and fire) and one power input into this subsystem. It will aim the launcher according to data sent from the interceptor controller subsystem. Once the mechanism is aimed at the proper point, it will load and fire a projectile when it receives the corresponding signals from the controller. This subsystem will receive approximately 3.3 V to

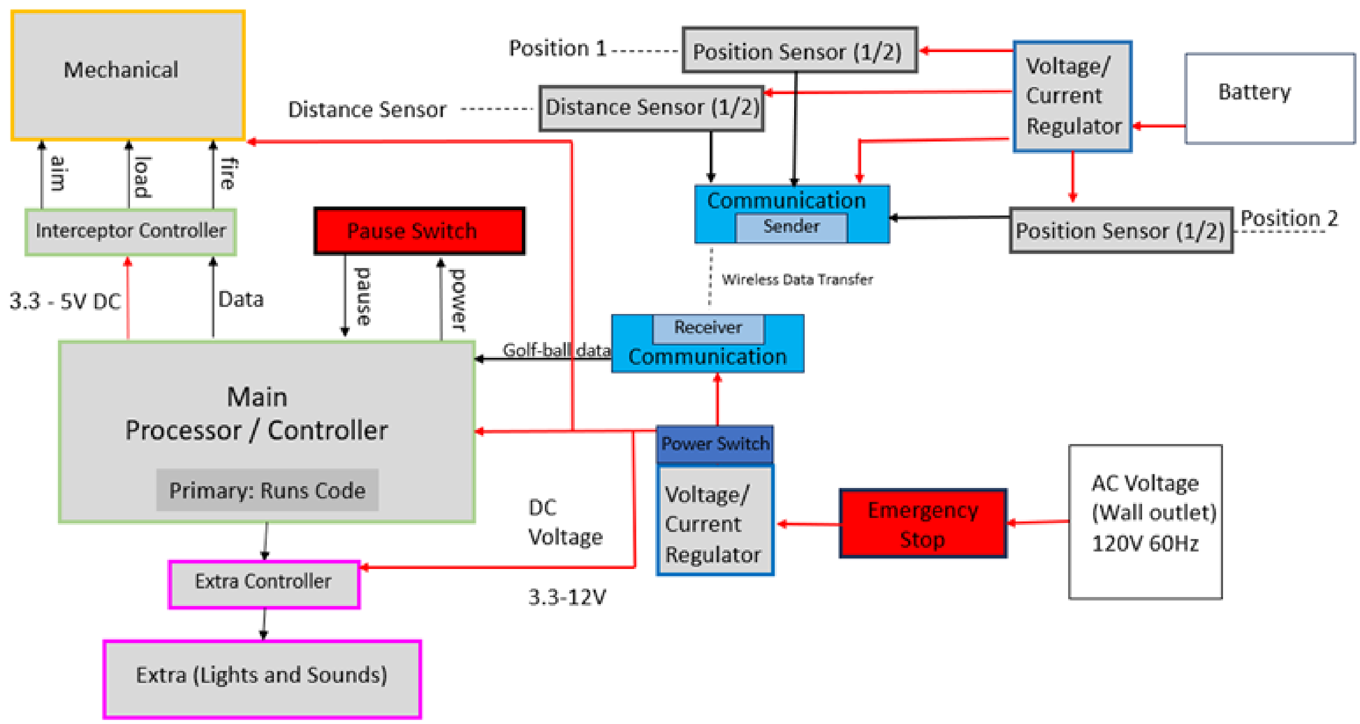

Fig. 1. Block Diagram

5 V from the voltage and current regulator in the device power subsystem. This is the least important subsystem because the mechanical team will be handling this portion of the project.

B. Device Power

The device power subsystem, the lower voltage and current regulator outlined in blue, will supply power to each of the other subsystems on the main launcher unit. This subsystem is fourth in line because it powers the brains of the interceptor. It will receive 120 V AC power from the E-stop which is getting power from the wall outlet. A power switch will also be added after the voltage regulator to meet the customer's requirements. It will then convert from AC to DC and output that power to each subsystem. This routed power will be regulated to 3.3 V to 12 V according to that specific subsystem's required voltage and current. The different routes include connecting this subsystem to the mechanical subsystem, processor subsystem, and the extra controller subsystem. This system must also be able to maintain these values as consistently as possible.

C. Battery Power

The battery power subsystem, upper right voltage and current regulator outlined in blue, will supply each sensor stand with sufficient and quality power. This subsystem is also fourth in line because it powers the sensors, which are highly important. This system will be on each of the stands. The main input for this system will be a battery pack that will supply sufficient voltage and current. The output of this system will be a regulated voltage in the range of 3.3 V to 5 V. This voltage depends on the specifications of the sensors that are chosen. This power must be maintained and must not fluctuate. A charging system is not needed because each battery will be removable and can be charged when needed. This subsystem will be properly analyzed with the available voltage tools.

D. Communication

The communication part of the design, noted by the blue color in the main figure, implements the wireless communication constraint of the project. This block is the third most important subsystem. While this system is once again required by the customer, the data that it will be transmitting is very important to the functionality of the design. The block diagram shows that the communication block is separated into two parts. The first part is located with the sensors while the second part is located with the processor and controller section of the diagram. The sensor side of the communication block receives two different signals. One of the signals, which comes from the battery management system, powers the transmitter which will be used to wirelessly send the data to the receiver. Due to the estimated speed of the golf ball, the estimated time it will take to launch, and the estimated processing time, the device will need a bandwidth of approximately 10.3 Mbps in order to relay the data in time. This calculation was made by plugging in the estimated values into equation 1 which is used to determine transmission speed.

$$speed = \frac{distance}{time} \tag{1}$$

This transmission speed was then plugged into equation 2 which converts the speed into bits per second. This equation is taught and used in the Computer Networks class. The bandwidth is assumed to be 1 Mbps.

$$speed(inMbps) = speed(in\frac{m}{s}) \times bandwidth \times 8 \qquad (2)$$

The second signal will be the data collected from the golf ball, this will include the speed and location of the golf ball. The output of the transmitter will once again be the data collected from the golf ball. The receiver has two inputs and one output, much like the transmitter. The two inputs will be power from the voltage regulator, and the golf ball data that has been wirelessly transmitted. The receiver will finally output the golf ball data to the processor which will act accordingly. This block accomplishes the wireless communication portion of the rules that we must abide by. Proper communication will be verified by establishing the connection, the bandwidth and proper functionality will also be tested using the available formulas.

E. Processor and Controller

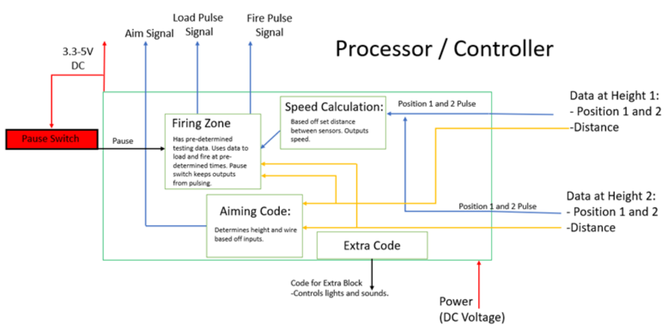

Fig. 2. Main Processor

The processor or controller section of the block diagram, noted by the green color, is considered to be the brains of the design. This block has been determined as the second most important because without it the mechanical portion would not be controlled. This would lead to a design that detects the ball but has no way to act upon that data. A more zoomed in version of the two main pieces of the processor block are also shown. There are eight different inputs to the zoomed in portion of the processor block. One input is the voltage, which may range from 3.3V to possibly 12V DC, from the current and voltage regulator. The most important data comes from the sensors. This data is broken down into two main heights. Both heights collect pulses from the two sensor posts and the distance, or wire that the ball is on. This data is then sent to the firing zone code block. The position pulses are sent to the speed block of code that determines the speed of the golf ball. That output is then sent to the firing block. The aiming code takes the distance from the two heights. Based on which height is asserted, the aiming code determines the height and wire that the golf ball is located at. The firing zone takes in the speed calculation, two distances, and the pause switch input. This block outputs the firing pulse signal and load pulse signal. Finally, the processor block outputs the load pulse, fire pulse, aim signal and the extra signal. The extra signal will be used if there is extra time available.

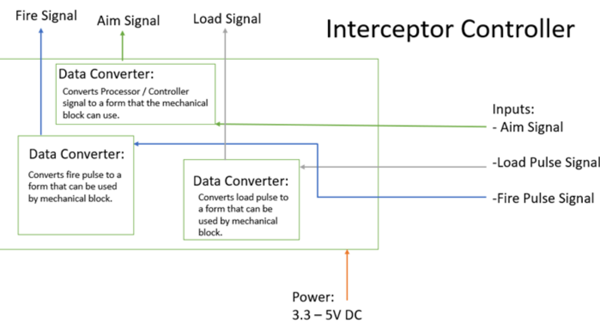

Fig. 3. Interceptor Controller

The next part of the processor is the interceptor controller. This block takes the outputs from the processor and converts it to a form that the mechanical portion can use. All the inputs go into a converter that will make the mechanical portion work properly. The aiming specifically will move the interceptor to one of thirty possible locations. The load signal allows the mechanical portion to load the projectile. Finally, the fire signal gives the mechanical portion the signal to fire the projectile.

F. Sensors

The sensor subsystem, as seen in grey, will consist of one or more individual sensors and will gather data from the golf ball as is slides down the fishing line. This block is of highest importance. Without proper sensing the processor block would have no data to act on. This system will determine the position and distance of the golf ball. This may be done with three sensors. Position sensor one is used to initially start a timer to determine the speed of the projectile while position sensor two will stop the timer. This process will allow the processor to gather the speed based on the distance and time that the golf ball travels over. Based on estimations and physics equations, a range for the golf ball's speed is from about 3 to 5 m/s ignoring tension. The specific equation used is shown in equation 3.

$$v = \sqrt{2 \times a \times d} \qquad (3)$$

The team will consider slightly higher and lower speeds depending on how the tension impacts the speed. Sensor three will be a distance sensor that determines what fishing line the golf ball is on. All these sensors will be powered by the voltage regulator which is attached to the battery management system. The voltage for this battery management system will be based on which sensor is chosen. This data will be sent to the wireless communication subsystem to be sent to the main launcher. The sensors will be at one of two variable heights, this is why the sensors are labeled with one and two in the block diagram. If the sensors are on the same post, then they will theoretically be able to share the same battery management system and voltage and current regulation system, but they will need different communication systems to ensure that the golf ball data makes it to the processor. Proper functionality can be determined by ensuring that the sensors are working correctly. This is important because the entire project hinges on the sensors functioning properly.

G. Emergency Stop and Pause Switch

The emergency stop and pause switch, noted by the color red in the block diagram, are two constraints that were added by the customer, Devcom. These systems are the fifth most important because, while they are required by the customer, they do not add to the complete objective of detecting and intercepting the golf ball. The emergency stop will take the input from the wall outlet and will allow it to pass unless it is activated. If the emergency stop is activated it will prevent voltage from passing which will deenergize our system. The pause switch, which will be implemented to pause the system to allow for the board to be reset, will be implemented with the processor. The switch will receive voltage from the processor and when it is engaged it will prevent the input to the interceptor controller from being passed. This will prevent the system from firing when the judges are in the game play area. This is expected to be implemented into the code of the processor to prevent instructions from passing to the interceptor controller. The emergency stop will be verified by ensuring that there is no voltage leaking into the system. The pause switch will be verified by ensuring that it properly pauses the firing mechanism.

H. Extra

The extra subsystem will only be included once the others are properly implemented; therefore, it is of the least importance. It is still important to consider how it works to ensure that it is quickly implemented if the time permits. This portion of the project will add points to the total score as seen in the rubric in the rulebook. The extra subsystem is controlled by the processor block. A voltage of approximately 3.3V to 12V will be supplied to power this subsystem from the voltage regulator. A data signal will most likely be sent from the processor block to the extra controller where it will properly control the extra block. This will control the lights and sounds that will be determined at a later stage. Other decorations may also be added to complete the decorations part of the scorecard.

IV. Gnatt Chart

While moving closer towards the detailed design, it is important for the team to have a more detailed idea of how the design process will go. Because of this, updates have been made to the predicted timeline to determine the start times and highlight what is currently being worked on. The timeline still consists of the design of specific sub-systems, the designated break over the summer, and plans for building the system next fall. The new timeline repersented in figure 4 was created to reflect a Gnatt chart to help manage the team's time and planning better.

V. References

[1] "What is FCC part 15.247 for Bluetooth/WLAN 802.11 b/g/n (2.4 GHz)?," Compliance Testing, https://compliancetesting.com/what-is-fcc-part-15-247-for-bluetooth-wlan-802-11-b-g-n-2-4-ghz/

[2] Federal Communications Commission § 15.247, https://www.govinfo.gov/content/pkg/CFR-2010-title47-vol1/pdf/CFR-2010-title47-vol1-sec15-247.pdf

[3] R. Stull, "IEC 60335-1 explained: Safety standards for household appliances," CUI Inc, https://www.cui.com/blog/iec-60335-1-explained-safety-standards-for-household-appliances#impact-on-power-supply-design

[4] "North American Voltage Ranges," Quick 220 Electrical Systems, https://quick220.com/pages/north-american-voltage-ranges (accessed Mar. 8, 2024).

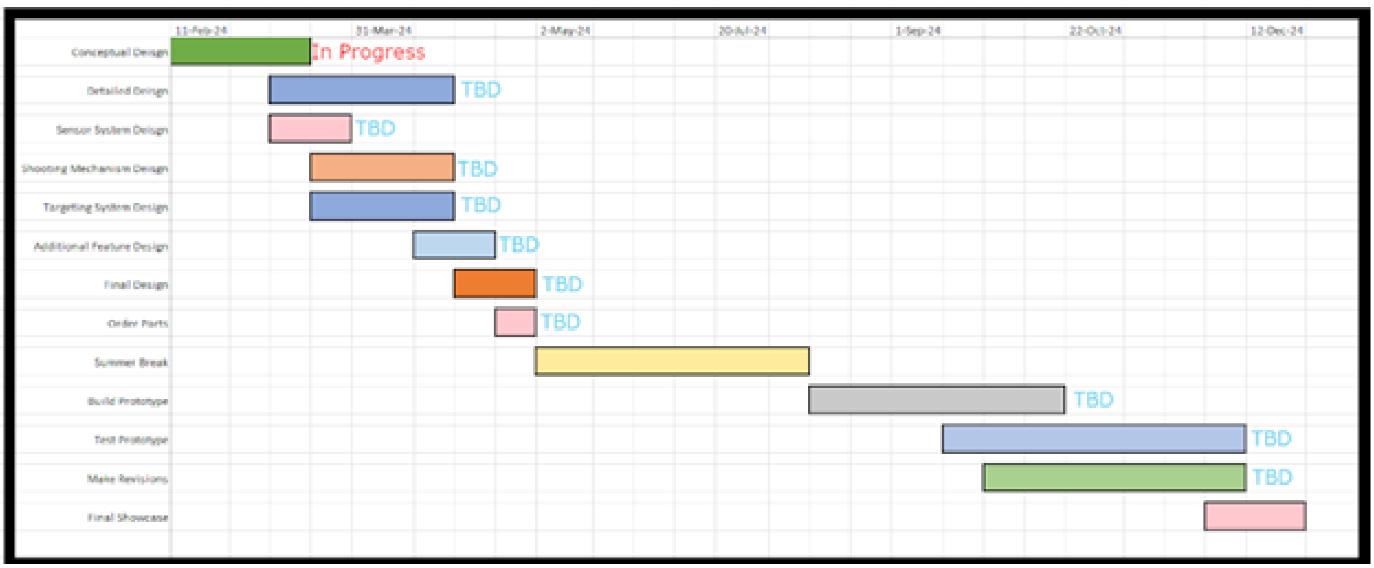

Fig. 4. Gnatt Chart