Computer Aided Design and Prototyping

(ME444 – SPRING 2024)

Table Foosball

Design Report

Group No. 20

Kashyap Subramanian	Junior - ME
Sidh Gurnani	Junior - ME
Cannon Elsbury	Senior - ME
Miguel Cremades	Junior - ME

School of Mechanical Engineering
Purdue University

Revision History

S. No.	Date	Revision ID	Revision Details (Page No., Paragraph, Line No. etc.)	Author
1.	4/26/2024	Revision A	Initial Release	All Members
2.	4/28/2024	Revision B	Subsequent changes made to the report are documented here	All Members

Executive Summary

The project required the development of a new toy with significant market potential. This toy was expected to feature significantly different attributes compared to existing toys in the market. Additionally, it needed to be a mechanical toy with sufficient complexity. Mechanical toys were required to showcase a minimum of two non-trivial mechanisms, while mechatronic toys were to incorporate at least one non-trivial mechanism. Both variants of the toy were expected to offer at least two non-trivial functions or actions to fulfill the project requirements effectively.

Keeping these requirements in mind, team 20 came up with the idea of designing a "Table Foosball" game. This game is inspired from Foosball and Pinball, two popular American arcade games. The game can be played by two or four players and the point of the game is to hit the ball into the other team's goal. The ball is to be hit using the "flippers", which can be operated by pressing the mechanical push buttons on the sides of the table. Additionally, there are blockers placed in the middle of the game area which pop up at random speeds and prevent a direct shot at goal. These blockers are moved by cams connected to a shaft. The shaft is rotated using a standard servo motor. When the ball eventually goes into the goal, there is a mechanical 'ball retrieval' system which is powered by gravity. The ball is funneled down to the side of the table, where it can be lifted manually using the 'ball lift mechanism'. Finally, there are two scoreboards on the side of the table which can be operated manually to keep tab of the score. An image of the Table Foosball CAD assembly can be seen in Figure 1 whereas the final assembly can be seen in Figure 2.

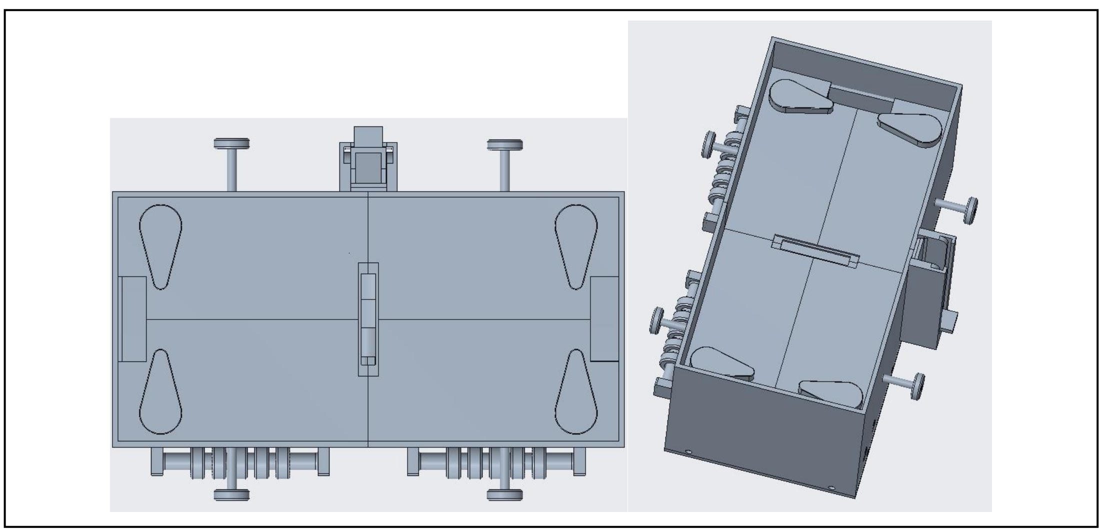

Figure 1: Table Foosball Project CAD Assembly

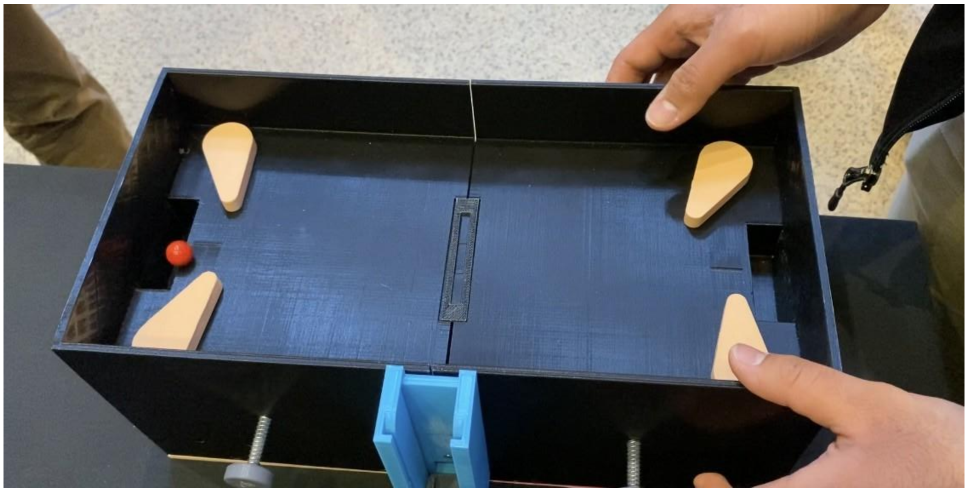

Figure 2: Table Foosball Project Final Assembly

Team 20 believes that there is a lot of market potential for this product. Foosball and Pinball are some of the most popular arcade games and this game combines the two concepts to provide a fun and unique playing experience. Its small size also makes it very portable and can become a household game.

The final toy assembly can be found at the following file path: ME444G20/Action Toy/CAD/Integration/final_cad_assembly.

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1. Introduction

1.1 Project Background

The Table Foosball interactive toy is inspired by the combination of two very popular and beloved games, foosball and pinball. The overall gameplay is influenced by Foosball with a slight variation to the gameplay mechanics influenced by pinball flippers. Foosball is a game traditionally played between 2-4 people with the objective of scoring the ball in the opposing team's goal. Miniature soccer players are mounted on rotated bars which are manipulated by the players to move the ball. To create a tabletop version of foosball, flippers are used to kick the ball instead of the miniature soccer players. This allows the game to be played without the need for a large volume of space for the game apparatus to occupy.

The main features of Table Foosball include a ball (or multiple), a contoured field the ball rolls on, flippers to kick the ball towards the opponent’s goal, sporadic blockers to create an obstacle on the field, goals which take the ball and funnel towards the retrieval mechanism, and a retrieval mechanism to put the ball back in play.

Gameplay is very intuitive for players without the need for complex thinking or strategy. The only limitation for players is the ability to push a spring-loaded button and lift a small, plastic elevator which houses the ball while it is being lifted back into the field of play, in addition the requirement of two people to play. Considering these limitations, almost any person, at any age is able to enjoy playing Table Foosball. Due to the engaging, dynamic nature of the game, with variability throughout gameplay, there is no end to the amount of delight people can attain from playing. This creates a very high play value for the toy and offers enduring entertainment value for countless years.

The only similar game on the market is a miniaturized version of foosball (shown in Appendix A1). This game offers the same gameplay as traditional foosball, scaled to fit most tabletops, with miniature soccer players still mounted on rotated bars which are manipulated by the players to move the ball. These games lack the innovative feature of actuating flippers used to kick the ball towards the opponents’ goal by pressing a button, rather they are limited to rotating a handle. This creates a very large market potential for Table Foosball, if it were to reach that stage in development.

1.2 Design Requirements & Constraints

The overall objective of the toy was to build a working prototype of an action toy by using advanced CAD tools and Rapid Prototyping techniques such as 3D printing. To clarify, an action toy means that it has to be movable, whether that be mechanical or involve mechatronics. The toy itself had to be novel and have some market potential. The toy also had to be complex and involve at least two non-trivial mechanisms.

There were some CAD requirements expected of the team, which are as follows. The team was expected to model all parts in CAD including all commercial-off-the-shelf (COTS) parts used. The mechanisms could also be simulated in Creo Parametric. The colors would also match the appearance of the toy.

The physical prototype had to be mainly made using rapid manufacturing processes, which was a limitation in terms of the manufacturing processes and time taken to manufacture. However, it did serve to allow complex geometry to be used and design iterations to be performed as necessary. The constraints included that the overall size had to fit within 10 x 10 x 10 inches (254 x 254 x 254 mm). This size dimension had ultimately negatively affected the outcome and the team had opted to slightly extend the size requirements to 180 x 360 x 150 mm. This allowed a playing surface that would be adequately long enough to enhance user enjoyment.

The last requirement that was put in place was to either source COTS from what was available or purchase a set of COTS that totaled to under $70.

The team had one main imposed requirement, which was to create a toy that was interactive, spontaneous, and intuitive. An action toy that isn't interactive can be easily designed, however the team wanted users to be able to interact with the toy. This idea served as the main motivation for choosing the table foosball concept, as it is a novel idea that had market potential, and served as an interactive toy that encourages friendly competition.

2. Concept Generation and Selection

When initially tasked with designing the table foosball game, preliminary sketches were made which contained the key functions and mechanisms. The preliminary design consisted of similar components and key features to the current toy but were eventually modified to improve gameplay and user experience. The preliminary design consisted of a flipper, ball retrieval mechanism, and blocker mechanism, although they were both heavily modified, without any scoring system. The original flipper, ball retrieval, and blocker mechanisms are shown sketched in figure 3.

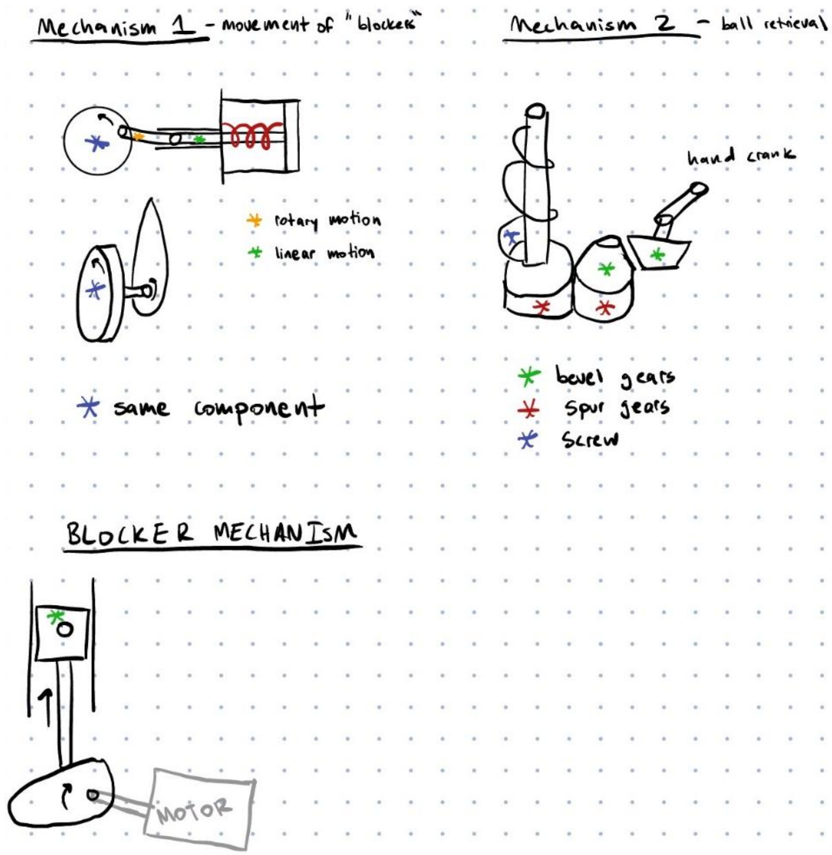

Figure 3: Original sketches of Flipper, Ball Retrieval and Blocker Mechanisms.

The designs of these mechanisms were later deduced, and the scoring system was added to create a complete toy. The flipper mechanism was modified based on integration with the exterior frame as well as assembly. The ball retrieval was modified from a screw and hand crank was modified to an elevator and shaft for quickness of retrieval and intuition for users. The blocker mechanism was kept as a CAM with a servo controlling the rotations.

3. Detail Design

3.1 Sub-system 1: Flippers

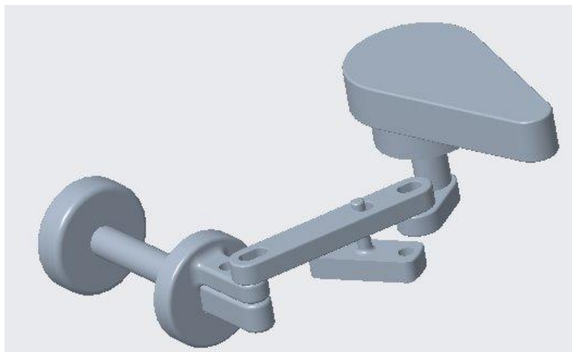

Figure 4: Isolated Flipper Mechanism.

The isolated flipper mechanism shown above in figure 4 is used to kick the ball towards the opponents' goal. In the full assembly of the toy, there are a total of four flipper mechanisms, one on each side of both goals. The actuation of the flipper mechanism starts by pressing the spring-loaded button which is exposed on the outside of the walls. There is a rod connected to the button which is attached to a slotted pivot. The linear motion of the button creates a rotational motion of the pivot, creating rotational motion in the opposite direction for the flipper to rotate. The position of the pivot was designed to rotate the flipper 60° when the spring was fully compressed, creating an ideal rotation to kick the ball forward. The magnitude and speed of the kick from the flipper is entirely dependent on how fast and how far the button is pressed. Connected to the button rod is a stopper to prevent retraction motion of the button due to the spring. This stopper is designed to leave the spring under a small amount of compression, so the spring is not loose, as well as orient the flipper to be perfectly horizontal when the button is fully retracted.

3.2 Sub-system 2: Ball Retrieval

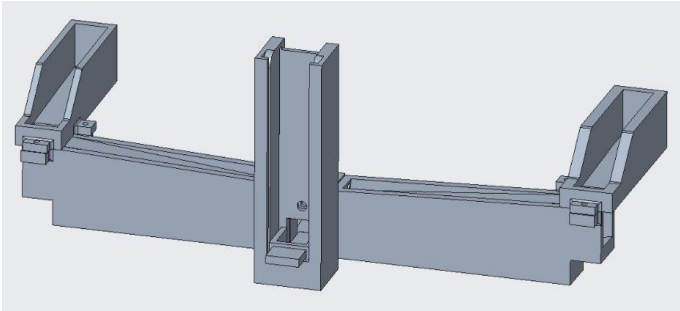

Figure 5 Isolated Ball Retrieval Mechanism.

The ball retrieval mechanism shown above in Figure 5 was designed to funnel the ball from the goal to a central location between players to then be put back into play. It was also very important the method of putting the ball back into play was objective and did not create a fair advantage for one player or another. Under these considerations, the ball was funneled to an elevator which housed the ball. The elevator could then be easily raised inside a vertical, slotted shaft to direct the elevator. Once the elevator reached the top where the ball could be put back into play, the vertical shaft had a stop on one side (closest to the field) but allowed free rotation on the other side (furthest from the field) which created a motion of “tipping a bucket” and the ball would spill over into the field of play. After the ball was put back into play, the elevator would fall back to the bottom, prepared for another goal to be scored.

3.3 Sub-system 3: Electromechanical Blocker System

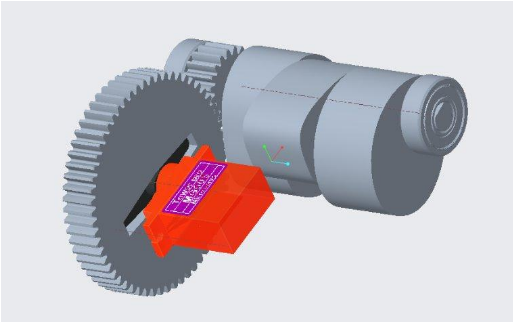

Figure 6: Blocker Mechanism with Servo Motor

The electro-mechanical subsystem was used to operate the blocker mechanism by controlling the shaft that rotates the cams. In order to rotate the shaft, a 180° standard Servo Motor was used and controlled with an ESP-32 microcontroller. The ESP-32 and Servo were powered by a 9V battery and since the voltage requirement for the Servo was 5 volts, a voltage regulator was used. Additionally, two basic switches were used: one was used for powering the circuit and the other was used to reset the positions of the blockers.

For the CAMs to rotate the full 360 degrees a 3 to 1 gear ratio was used, and the servo was made to go from 0 to 120 and then to 0 degrees over and over to raise the blockers. The servo was also used to reset the blocker position to the point where they were flush with the playing surface when hitting the reset switch.

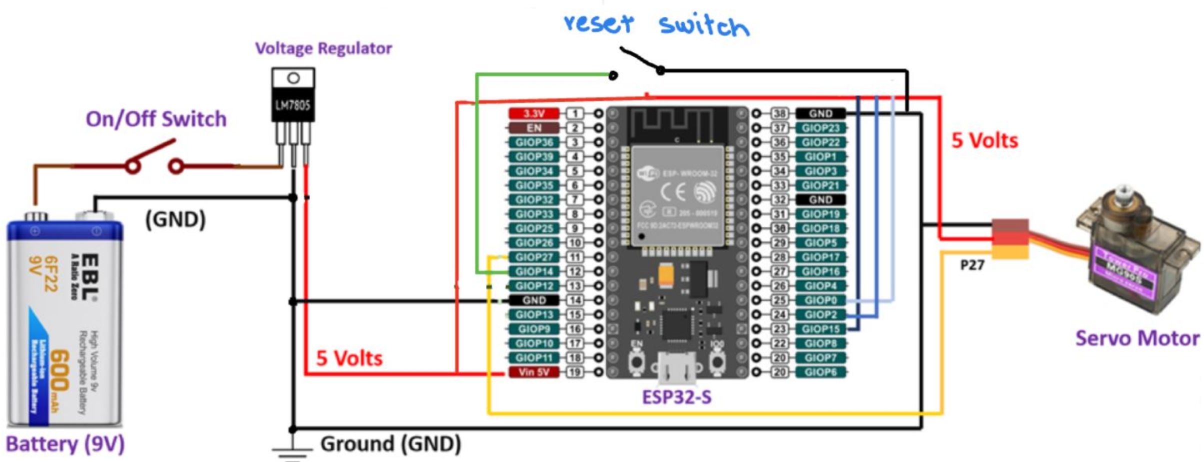

Figure 7: Circuit Diagram

Summary of Components Used:

1. ***Servo Motor (180°):*** *Rotates shaft to control the blocker mechanism.*
2. ***ESP-32 Microcontroller:*** *Controls Servo motor's rotation.*
3. ***Voltage Regulator:*** *Steps down 9V battery power to 5 volts for Servo motor.*
4. ***Basic Switches (x2):*** *One powers the circuit, the other resets blocker positions.*

3.4 System Integration

The process of integrating the subsystems can best be described as understanding the individual subsystems, how much space they require, how they would interface with one another and the overall system, before designing the shell of the toy. Overall, the toy was designed with a bottom-up approach once the initial concepts had been generated. There were three main phases that were undertaken with systems integration: 1) an initial model of the shell that served as the basis for integration, 2) putting together a CAD assembly to see how everything would interface, and 3) assembly and testing.

Before any subsystems were modelled in Creo Parametric, the team discussed the initial size of the toy to better understand how much volume that each subsystem had to be as well as a design constraint of how large the overall toy had to be. While discussing this, the team concluded that a size of 360mm by 180mm by 150mm was appropriate. While this was larger than the design requirements, the team felt that this size was appropriate to provide a good playing experience for the players. From that point, there were several considerations made for how the shell should be designed to accommodate the manufacturing methods that were available to us. Since a larger enough 3D printer was not available, the shell had to be split. The team finalized four pieces, where the base and top were split into two halves each. From that point, an initial CAD model and assembly were created.

As all the subsystems were being created, the shell was being constantly updated with any holes required for hardware as well as placement of all subsystems. In addition, support was created for the CAM assembly, as it required additional support to ensure that the rotational energy coming from the servo wouldn't be wasted. Once all the subsystems were in place and all supports were created, the overall assembly was mostly done. Space for additional accessories such as the battery, breadboard, wires, and switches had to be considered as well as places to put each of these and routing wires and switches were considered.

Once an entire CAD assembly was created, fabrication began, and any prototyping and testing that was required could begin. This is discussed in more detail in the following section.

4. Prototyping and Testing

The prototyping consisted of a combination of fabrication via 3D printing as well as any commercial-off-the-shelf (COTS) products that had to be purchased. All the COTS that were provided with the midterm project were used, and the team did not have to acquire any other COTS from other sources. Other required items such as the ball that would be used in play as well as springs for the buttons were acquired from what was already available. This means that the team did not have to use any of the $70 budget that was allocated specifically for buying COTS parts that were not readily available. While a DC motor was initially considered, a servo motor was selected over a DC motor as it allowed for control over the rotation angle. Bearings were also reused from the midterm project.

The manufacturing of the prototype came entirely from 3D printing, using what was available to the team in the form of the Mechanical Engineering 3D printing lab. The materials that all parts were fabricated from was PLA, as it is something that was durable and readily available. Initially the team had considered using plywood for the playing surface and shell, but due to a requirement to have a contoured playing surface, 3D printing was chosen to ensure ease of assembly and more design freedom. In addition, the design of the shell, which the team was aware that would take the most time to print, was designed entirely with 3D printing in mind to reduce the fabrication time and ensure minimal post-processing. To ensure proper fitment, tolerances were considered, with up to 0.5mm of clearance left in most places, and 0.2mm to 0.3mm of clearance left in places that needed a tighter fit. The team had considered DFM principles while designing the CAD, however the team could have better accounted for DFA, specifically with tool sizes. To elaborate, the team had considered the hardware that needed to be used and to an extent, the size of the hardware required (i.e. proper length of bolts) but failed in some places to consider the size of the tools such as the Allen wrenches to be able to properly assemble the toy. There were many such difficulties that were encountered, and they are detailed below, being split up by subassembly.

Before the installation of the flippers, the team had to redesign the button system and reprint it to account for the fact that it had to fit through a hole in the shell. At the point it was redesigned, the shell had already been printed, and therefore the flipper system had to be reworked. The installation of the flippers did not fully consider the size of the tools that were being used during the installation process, something which has been emphasized that could have been done better. There was minimal space to put a bolt through the subsystem due to restrictions imposed by the placement of the playing surface. Therefore, the bolts had to be installed the opposite direction than initially intended in some cases, while in other cases, were installed the initially decided upon orientation with great difficulty. A second issue that came about with the flipper subsystem was with the pivot point. The flipper assembly and the shell were printed using different printers, which did not translate to the finished product as expected. Therefore, the team had to forego using the initially designed pivot point and settle for a screw that was put in its place.

The ball retrieval system had experienced one main issue, which came about once again due to the difference in 3D printers used for the interfacing components. One of the holes had lined up in the appropriate mounting point, while the other one was not. But issues with considering DFA meant that instead of using two screws like initially intended, the team had to super glue the system in place. During assembly, a smaller issue arose where the lift could not fit into the appropriate component and required post processing to ensure that it would fit and work as expected. There was also one minor issue the fabrication that had occurred, where the layers had shifted slightly and caused a ridge to form in the railing. This was a minor issues and not one large enough to warrant reprinting, therefore the team used it in the final iteration.

The CAM and blocker assembly went through a few iterations as minor issues arose during testing. A blocker guide was used to help align the blockers and keep them in plane. The first blocker guide was not long enough and could not keep the blockers in plane. This meant that when the blockers had to be driven the opposite direction by the servo motors, that the blockers would get wedged in between the CAMs and cause it to get stuck, thereby forcing the servo motor to have to rotate the entire toy. This wasn't ideal and the guide had been redesigned to be longer to prevent the blockers from falling out of plane. The blockers themselves also went through a change, as the initial blockers were not well toleranced and were too short. The team had adjusted a few dimensions and reprinted the blockers. The blockers still had to undergo post processing (sanding down) to ensure proper fitment. There were also a few fabrication issues along the way with the CAMs and the CAM shaft, which were down to supports used that were not ideal and tolerancing issues early on. After changing dimensions and reprinting, most of the issues were solved. However, post processing (sanding down) was also required to ensure proper fitment. All of these issues early on meant that when the CAM and blocker assembly was put together, there were minimal teething issues. Upon complete assembly, the only thing that had to be changed was recalibrating the zero point for the servo, which was as simple as changing a few numbers in the code.

The last major issue that arose was the fabrication of the scoreboard. It was initially designed to be able to print in one piece, and after several failed attempts at fabricating, the team had redesigned the scoreboard to have multiple pieces and to be able to more easily fabricate with 3D printing.

Once all the issues had been resolved or a workaround had been established, the assembly was a relatively straightforward process, and the toy was able to be put together successfully. There was, however, one issue with intersecting subsystems that was avoidable in hindsight. A very later addition to the project was holes that were created in the body to accommodate the two required switches. However, it being a last-minute addition meant that it was placed in a location where the ball retrieval system was running. This meant that the switches had to be routed through an opening between the base plates and top shells.

5. Results and discussion

For the prototype that was presented there were a few issues that can be solved by doing more iterations of it. The playing surface for example should've been slanted more towards the goals and away from the walls by designing a better surface finish. The ball retrieval system got the ball stuck several times so a smoother guide should be designed that doesn't contain as many right angles. The flippers were unreliable and after enough use would end up breaking so a more optimal design can be created for them. For the blocker system a better motor should be used for it to have a slower turning rate but with it still being a continuous motion. Further consideration of the importance of the reset switch should be made to determine if it's necessary for the toy. There are lots of issues that could be solved by creating another prototype that optimizes and makes each subsystem more reliable and durable.

If the team had one more prototyping cycle, there would be more consideration for assembly. Extra space would have been added to ensure proper assembly and components could be better designed for longevity in mind. In addition to all of the DFA issues mentioned earlier, more emphasis would have been placed on the aesthetics of the overall toy. That is something that was overlooked during the prototyping phase and was never considered during the design cycle. A simple example of an aesthetic change that could have been made would be to round off some of the rougher edges and perhaps design something like a sticker sheet that would cover the toy and enhance the looks of the toy.

While the team had learned a lot during this design cycle, there was one main takeaway, which was to keep in mind DFA. The team had improved significantly from the midterm project with regards to assembly concerns but could have improved even further on that.

6. Conclusion

This project helped the team to know what issues may arise in the assembling stage and how to communicate properly to fit all subsystems into an assembly. It also helped to improve time management skills since there was definitely an improvement from the battle bot project. The team was able to put their respective skills together and build an action toy with distinct mechanisms while having most of it work. There should've been more communication between the members for everyone to decide what would be the most optimal solution for each system rather than completely assigning one mechanism to a single person. There could've been better design solutions to each system if everyone in the team proposed ideas on how to design each mechanism. In the future every member will now be more expressive about whether or not they believe something could be designed better to reduce complications.

7. References

1. Arduino. "Servo Motor Basics with Arduino." *Docs.Arduino.Cc*, 4 Mar. 2024, docs.arduino.cc/learn/electronics/servo-motors/.

8. Appendices

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Relevant material non needed for average reader for example –

- *Part Drawings*

No specially manufactured parts apart from 3D printed parts.

- *Assembly Drawings*

No specially manufactured parts apart from 3D printed parts.

- *BOM*

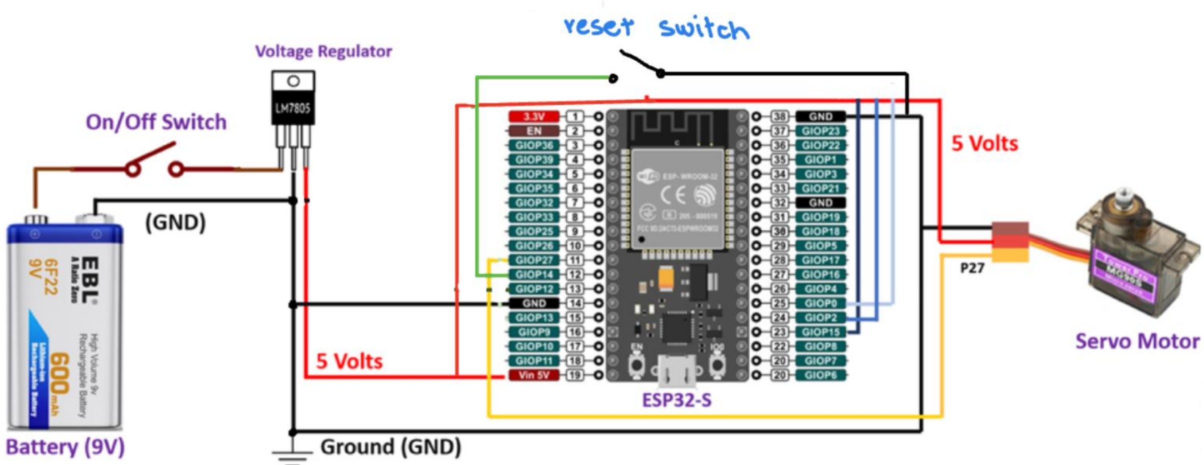
Component	# Used	Cost ($)	Total Cost ($)
Standard Servo Motor	1	Already Had	$0
ESP – 32 Microcontroller	1	Already Had	$0
Voltage Regulator	1	Already Had	$0
Basic Switch	2	Already Had	$0
9V Battery	1	Already Had	$0
Small Breadboard	1	Already Had	$0
M3x0.5x20mm Bolt	24	Already Had	$0
M3 Nut	24	Already Had	$0
22x8x7mm Bearing	4	Already Had	$0
0.6x7x30mm Spring	4	Already Had	$0

Total	$0

- *Manufacturer Datasheets for COTS parts (mechanical and electronic)*

No COTS parts used.

- *Circuit Diagram*



- *Arduino Code*

```
#include <ESP32Servo.h>


// Defining pins
int servoPin = 27;
int buttonPin = 2;
```

```
Servo servo1;

void setup() {
 Serial.begin(9600);
 delay(100);
 servo1.attach(servoPin);
 servo1.write(0);
 pinMode(buttonPin, INPUT_PULLUP); // Set button pin as input with internal pull-up resistor
 randomSeed(analogRead(0));      // Seed the random number generator
}

void loop() {
 //Serial.println("Go servo");
 int rand_num = random(5, 15); // Generate a random number for each iteration
 int num_test;
 // Move servo from 0 to 180 degrees
 for (int i = 0; i <= 138; i += rand_num) {
  num_test = i;
  Serial.println(rand_num);
  servo1.write(i);
  delay(100);
  // Check if the button is pressed
  if (digitalRead(buttonPin) == LOW) {
   servo1.write(0); // Move servo to 0 degrees immediately.
   while (digitalRead(buttonPin) == LOW) {
    delay(10); // Wait for button release.
   }
   break; // Exit the loop.
  }
```

```
  }
 Serial.println("angle = " + num_test);
 delay(1000);

 // Move servo from 180 to 0 degrees
 for (int i = 138; i >= 0; i -= rand_num) {
   servo1.write(i);
   delay(100);
   // Check if the button is pressed
   if (digitalRead(buttonPin) == LOW) {
     servo1.write(0); // Move servo to 0 degrees immediately
     while (digitalRead(buttonPin) == LOW) {
       delay(10); // Wait for button release.
     }
     break; // Exit the loop.
   }
 }
 delay(1000);
}
```

A1. Miniaturized Foosball