Mario Kart Automaton
MSE 428 - Project Report

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1 Abstract

The MSE 428 project required teams to develop a automaton to tell a story implementing a variety of mechanisms introduced in class. Through the use of the weighted value decision matrix, three different concepts of Mario Kart animations were evaluated and we quantifiably selected the concept Mario Kart animation story. The automaton chosen features a "Shy Guy Beach" themed Mario Kart moved using a pulley mechanism, "Bullet Bill" motion created using a slider-crank mechanism, "Flying Bomb" mechanism using a 4-bar linkage mechanism to simulate a arc movement, "Koopa Shell" using a slider-crank mechanism in perpendicular movement to the cart, and a cam mechanism to actuate harmonic motion of ocean waves. These mechanisms together will tell the story of a Mario Kart finish line race with impediments. The system was modelled on Solidworks in detail using VEX components and custom designed components to aid in accuracy and alignment of the physical model. In analyzing the automaton animation, mechanism synthesis was defined for the pulley belt system, slider-crank mechanisms implemented, four-bar linkage mechanism, and cam mechanism implemented. Detailed component value dimensions were used to define the component shape and attributes in Solidworks components to be manufactured in the physical model. A motion flow chart was developed to visually characterize the motion transmission provided from the input (input crank handle) to the output mechanisms. The gear train and power transmission method developed were complex and analyzed in order to narrate the Mario Kart finish line story. Displacement analysis plot was developed to relate the position of mechanical components of interest to the angular position of the input crank. The plot shows the initial position and offsets of mechanism components which allows for analytical position analysis. The physical mechanical system was built, developed and tested for optimal performance. Most changes were made to allow the system to have better gear alignment and mechanical rigidity.

2 Introduction

The MSE 428 course project requires teams to build a automation in the form of a mechanical toy for young children that tells a story. Automatons are mechanical devices composed of mechanisms which are generally made to have a visual appeal through mechanical movement in a series of operations[1]. These type of devices have been cited as early at the 3rd century in China where intricate devices were made for the emperor of China [1]. In MSE 428, we have been introduced to a variety of simple mechanisms such as the four bar mechanism, cam-follower and slider-crank for example, which will be employed to design and automaton to tell a story.

Our group members agree that a common childhood memory involves countless hours playing Mario Kart. This video game involves several characters from the Mario universe go cart racing with special traps and tricks along the way. Mario Kart, like similar childhood video games, has a variety of unique game playing modes, active tracks and characters in the game which will allow our group to conceptualized and build a unique automaton using the mechanism concepts introduced in class. After developing and modelling a concept, we will analyze the system for synthesis of mechanisms, motion flow, displacement analysis and perform physical testing/evaluation.

3 Design Objectives and Constraints

The design objectives and constraints of this project are listed below:

- Build an automaton where all the components are operated by turning a crank
- Employ at least three families of mechanisms

  Ex. linkages (are a must), slider crank, cams, gears, Geneva wheels, Scotch yoke etc.
- Automaton must have at least five mechanisms
- Automaton must have at least three animated components ('tell the story')
- Teams must not exceed $80.00 CAD dollars
- 3D printed components are acceptable
- VEX Robotics gears and shafts must be used

4 Design Alternatives

4.1 Concept A

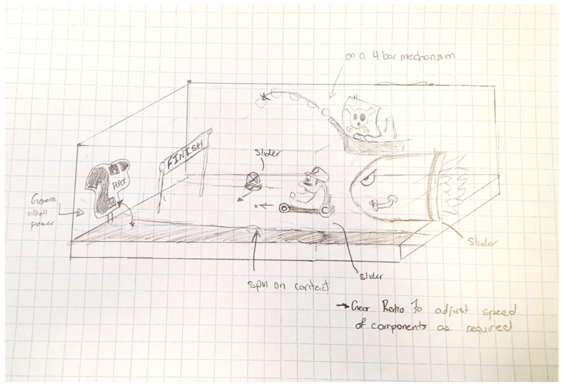


Figure 1: Concept A: Mario Kart Finish Line Animation

Concept A will tell the story of being in first place in a Mario Kart race for the entire game and then losing to someone that got the bullet bill item at the last second. This tragedy will take place on the popular map Shy Guy Beach. In the vertical stretch to the finish line there will be various obstacles like a Bomber Bill and a Koopa shell which will mechanically be simulated.

Families of mechanisms:

1. Gears
2. Linkages
3. Slider Crank (x2)
4. Cam-Follower

Mechanisms employed:

1. Four Bar Mechanism
2. Slider Crank (X2)
3. Gear Transmission with Crank Shaft
4. Cam-Follower
5. Pulley System

Animated components:

1. Mario Kart to finish line
2. Bullet Bill (bomb) to finish line
3. Flying bomb from ship
4. Koopa shell in the parallel axis to finish
5. Ocean wave harmonic movement

4.2 Concept B

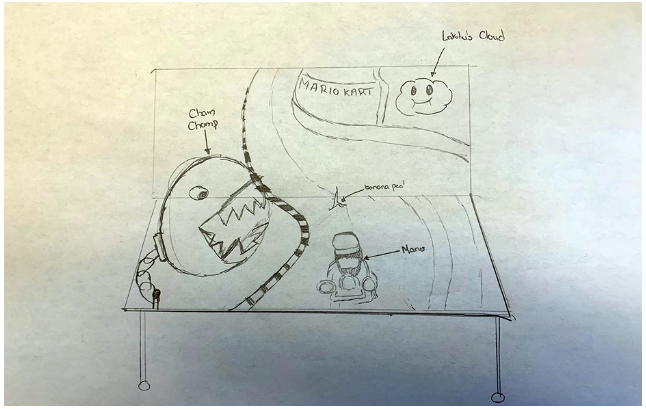


Figure 2: Concept B: Mario Kart Stadium race concept

Concept B we will tell the story of Mario travelling on a go cart in Mario Kart Stadium in which there will be a 'Chain Chomp' chomping bomb which perpendicular to the cart motion will move to impede Mario. There will be a banana peel on the track which on contact will see the Mario launch off the course. Another animation will be the Lakitu's cloud which will move up and down.

Families of mechanisms:

1. Gears
2. Slider Crank
3. Cam-Follower
4. Pulley
5. Actuation

Mechanisms employed:

1. Slider Crank
2. Gear Transmission with Crank Shaft
3. Cam-Follower
4. Pulley System
5. Spring Release Actuation

Animated components:

1. Mario Kart on the track
2. 'Chain Chomp' perpendicular movement
3. Mario Kart spring actuation up on banana peel contact
4. Koopa shell in the parallel axis to finish
5. Lakitu's cloud cam following movement

4.3 Concept C

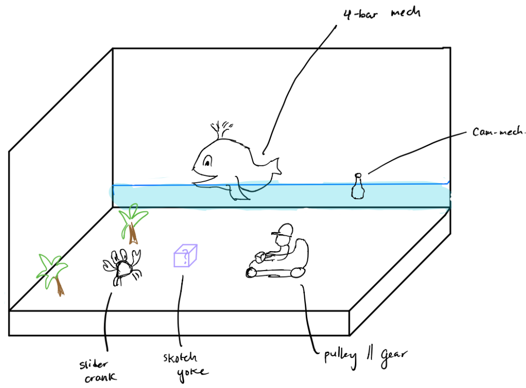


Figure 3: Concept C: Mario Kart Item Crystal and Obstruction Crab Animation

In this automata concept, we are telling the story of choosing between hitting the item crystal and hitting the obstruction crab, or just overall dodging the two items all together. This scenario will occur on the "Cheep-Cheep Beach" track. If Mario chooses to get the item, he will hit the obstruction crab and spin, displaying the common greedy player in this game, in which everything will be mechanically simulated.

Families of mechanisms:

1. Gears
2. Linkages
3. Slider Crank
4. Cam-Follower
5. Skotch-Yoke

Mechanisms employed:

1. Four Bar Mechanism
2. Slider Crank
3. Gear Transmission with Crank Shaft
4. Cam-Follower
5. Skotch-Yoke

Animated components:

1. Whale jumping from the ocean
2. Bottle floating in the ocean
3. Item crystal jumping up
4. Obstruction crab moving side to side
5. Mario kart travelling a straight path

5 Design Selection Method

In order to select the design concept for the project, we use a decision matrix with the following criterion and weighting to evaluate the concepts. The scores of each criterion will be normalized to the highest scoring concept. The highest scoring weighted concept will be selected.

- Valid system meeting design requirements (Weight: 35) - Meeting the design requirements of the project, in particular using at least three families of mechanisms, have at least five mechanisms implemented, having linkage mechanisms and three animated components.
- Number of mechanisms (Weight: 20) - Number of mechanisms employed. The greater the number of mechanisms the higher the score.
- System complexity (Weight: 20) - Evaluated considering the mechanisms implemented and positioning and use of the mechanisms.
- Manufacturability (Weight: 15) - Evaluated considering the complexity of the system components and physical manufacturability of the system including spacing of components and hardware required.
- Story Portrayed (Weight: 10)- Personal opinion of the originality of the story implemented.

TABLE 1: DECISION MATRIX

Criterion	**Weight**	**Concept A**	**Concept B**	**Concept C**
Valid System meeting design req.	35	35	0	35
Number of Mechanisms	20	20	20	20
System Complexity	20	20	15	10
Manufacturability	15	12	15	13
Story Portrayed	10	10	9	8
Σ	100	97	59	86

Using the scoring matrix above, it is shown that Concept A received the highest score. It scored perfect in all aspects of design requirements, mechanisms required, complexity, and story portrayed. However, it received a lower score in manufacturability due to the difficulty of spacing the components, for example, fitting in multiple bevel gears, and the need of a 3D printer to manufacture the parts to the appropriate size.

6 Detailed Description of Automaton

The automaton selected will illustrate the finish sequence of a Mario Kart race on the "Shy Guy Beach" map. The components to be illustrated include the Mario Kart, Bullet Bill, Flying Bomb, Koopa Shell, and ocean waves.

The Mario Kart movement will be created using a pulley mechanism which creates the shape of a straight line lap. The pulley parameters will be chosen to have a uniform ratio of pulley turns for each lap.

The Bullet Bill motion will be created using a slider crank mechanism which will run parallel with the Mario Kart. A gear ratio and time ratio will be implemented to ensure its velocity is faster than the Mario Kart's and that it crosses the finish line first.

The Flying Bomb is unique feature to the map "Shy Guy Beach", using a 4 bar mechanism, an arc motion will be created to illustrate bombs being launched off a distant ship in the ocean.

The Koopa shell will be animated using a simply slider crank mechanism. Since it will be bouncing back and forth, its gear ratio will be adjusted to actuate multiple times during the animation of the Mario Kart movement.

The wave movement will be created by mounting the waves to a revolute pin joint, and using a harmonic motion cam mechanism to create angular rotation of the waves.

7 CAD Design

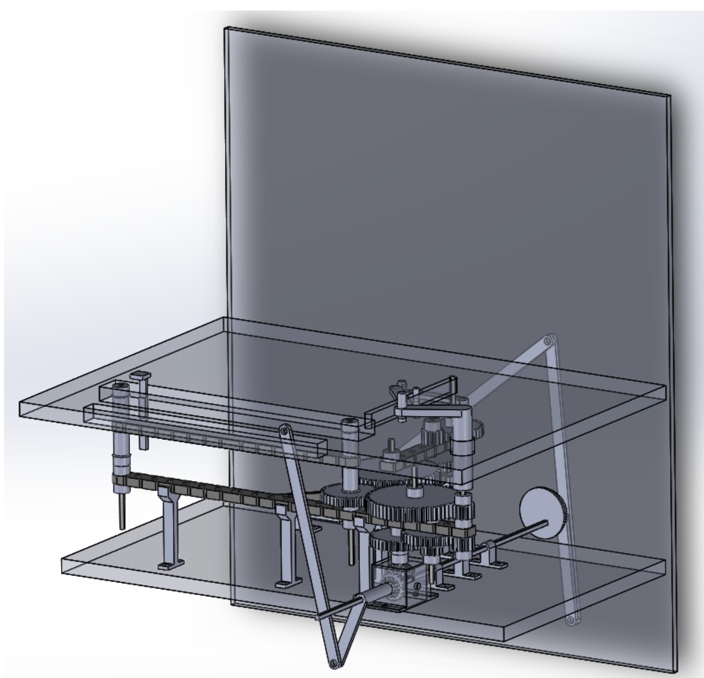


Figure 4: CAD Design Isometric View

The CAD model was essential to the execution of the project due to the additive manufacturing of many of our components other than the VEX components. The entire system was designed and modelled in SolidWorks before constructing. This aided in the accuracy and alignment of the final build.

Most notably, the VEX component structures, slider crank mechanism links, 4-bar mechanism links, cam mechanism, bevel gear housing, and supports for the entire structure were designed for the CAD model to be 3D printed.

8 Automaton Analysis

8.1 Synthesis of Mechanisms

To synthesize each component of the Automaton, the track length should first be defined so that all other components can be combined to be proportional to the track size. The MATLAB code used to synthesize each of the mechanism are included in the Appendix.

Mario Kart Track

The Mario Kart track pulley design was designed to fit the size scale of our project,the parameters of our sourced pulley belt (rubber band), and an appropriate pulley ratio. These constraints were used to calculated the pulley diameter and center distance.The constraints were as follows:

- a center distance near 20 cm
- a total track length slightly greater than our rubber band length of 35.56 cm
- an appropriate rubber band stretch to add tension, avoid bending
- a pulley ratio providing a reasonable number of input cranks turns per track lap

This resulted in:

- a center distance of 181.427 mm
- a pulley diameter of 10.5 mm
- a rubber band stretch of 20.1203 mm

Koopa Shell Slider-Crank Mechanism

To synthesize the slider-crank mechanism for the Koopa Shell, a time ratio of 1 is desired to create a linear movement back and forth, which means no offset. Additionally, we wanted our shell movement to be proportional to the track length, resulting in total displacement of 10 cm. However, solving for these specifications results in a mechanism whose input link length equalled the output link length. This was physically not possible for us to build since it would cause interference during the overlap of the output position and the input rotation axis at minimum position.

Bullet Bill Slider-Crank Mechanism

For the Bullet-Bill slider crank mechanism, we desired a time ratio so that the travel of the Bullet Bill would be faster on the output stroke than the return, the offset was determined by the distance of the drive shaft to the surface of the track from our SolidWorks model. This resulted in the following design specifications:

- Offset = 97 mm
- Time Ratio, TR = 2.9722

We input these parameters into the matlab file (attached). This resulted in the following link length values.

- Input Link = 52 mm
- Output Link = 160 mm

Bomb 4-Bar Mechanisms

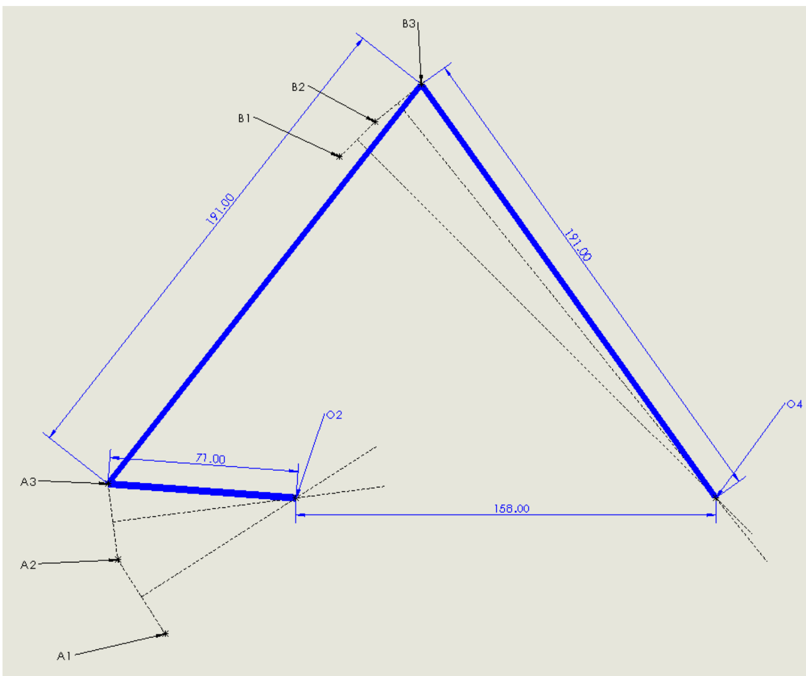


Figure 5: 4-Bar Mechanism Synthesis

To synthesize the 4 bar mechanism, we used the procedure from Chapter 2 page 12 from the lecture notes. This procedure is shown in figure 5. The motion generation precision points were chosen so that the output links position follows an arc to resemble the path of the launched bomb, while the input link precision points were chosen to have a small input link to minimize the vertical space needed beneath the Automaton. The resulting links are as follows:

- Frame Link, R1 = 158 mm
- Crank Link, R2 = 71 mm

- Coupler Link, R3 = 191 mm
- Follower Link, R4 = 191 mm

Ocean Wave Cam Mechanism

In order to implement the Cam mechanism for the ocean wave harmonic movement, we use the Cam PRF matlab software introduced in Lab 4. The parameters were selected around the desire to have 20mm of vertical motion in the wave foam board design which was modelled as a flat-face follower and choosing simple harmonic motion for the two intervals in-order to effectively model harmonic movement of a ocean wave. The following parameters are used to define the system:

- base circle diameter (mm): 30
- offset (s) (mm): 6.36
- cam rotational speed (rad/s) : 10
- Interval 1

    intial angle: 0

    final angle: 180

    motion: simple harmonic motion

    rise: 20 mm
- Interval 2

    intial angle: 180

    final angle: 360

    motion: simple harmonic motion

    fall: -20 mm

Cam PRF generated plots for the motion of cam-follower system are:

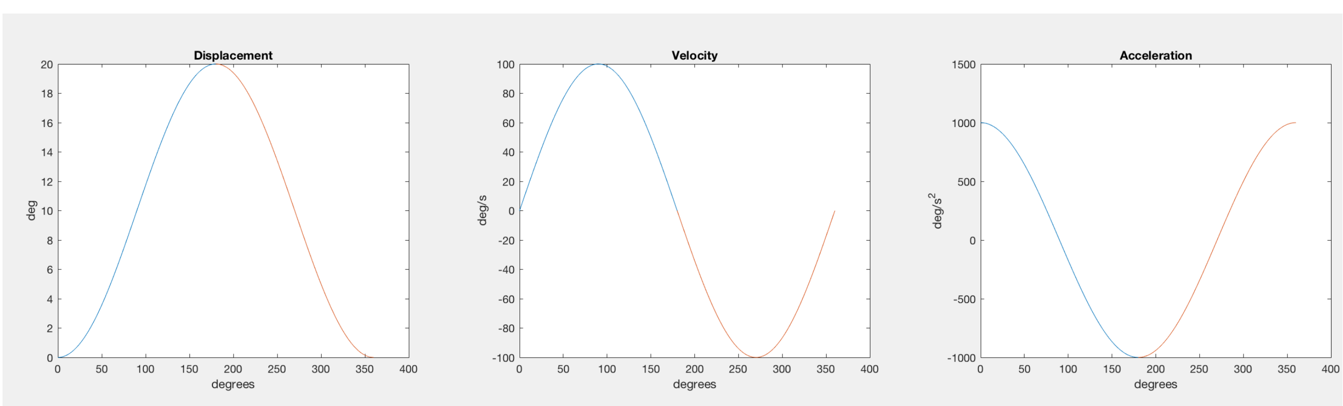


Figure 6: Cam PRF output plots - displacement, velocity, acceleration

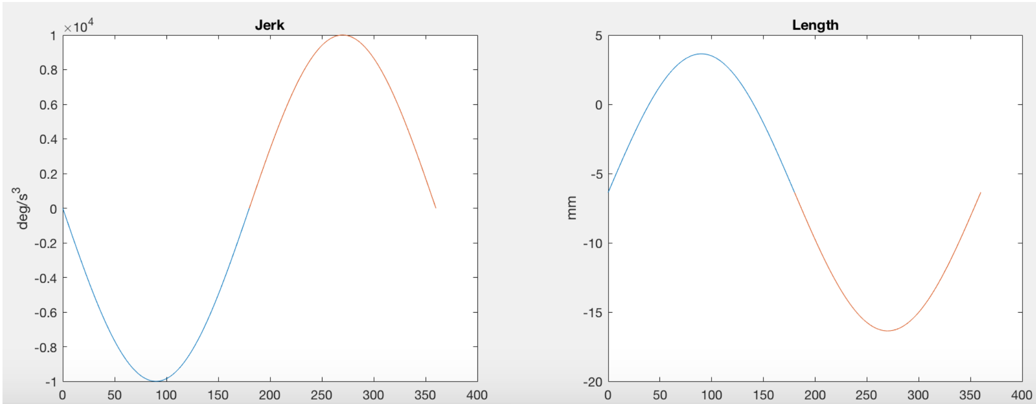


Figure 7: Cam PRF output plots - jerk, length

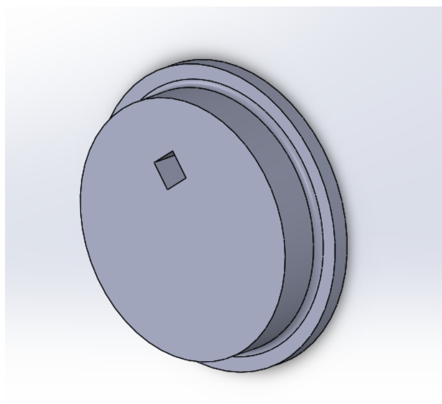


Figure 8: Cam profile implemented

8.2 Motion Flow Chart

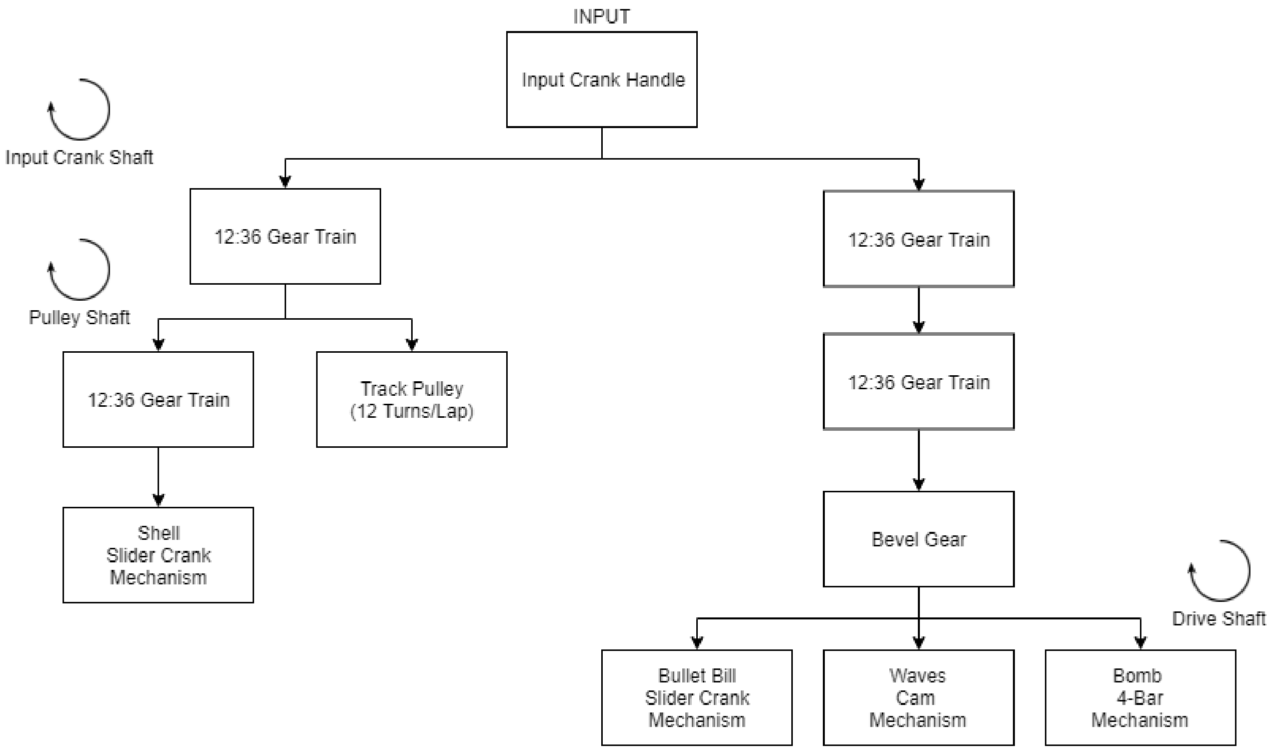


Figure 9: Motion Flow Diagram

The motion transmission proved to be one of the most difficult components of the project. As seen in figure above, the motion transmission involved a series of gear trains for gear ratios and displacements, along with pulleys and bevel gears to transmit motion to our animated components. A key specification of our motion transmission system is that the animated portion of the automaton is half of the pulley path (one end to the other). This is to avoid complications in timing due to slipping of the pulley mechanism.

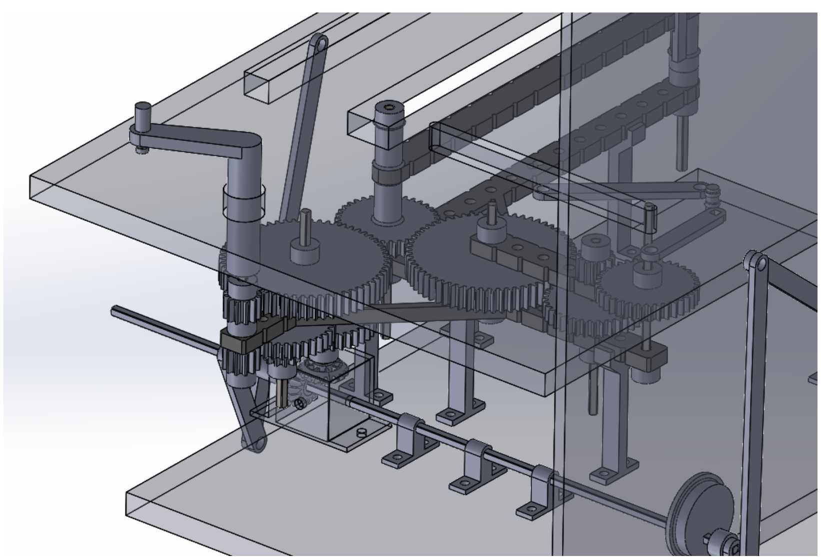


Figure 10: Pulley Motion Transmission

From the input shaft, there are two main paths, one leading towards the pulley mechanism, the other towards a set of bevel gears to create motion in a perpendicular axis drive shaft. The path from input crank to pulley has a gear train with a gear ratio of 1:3 (12T:36T) to increase the amount of input crank turns per lap, and decrease the amount of input torque needed, and a displacement in the x direction to ensure the input crank does not interfere with the movement of the Mario Kart. Following from the shaft connected to the pulley is a gear train with a gear ratio 1:3 (12T:36T) to increase the amount of actuations of the Koopa shell per lap, and a displacement in the -z direction to create offset from the track path for the Koopa Shell slider crank mechanism.

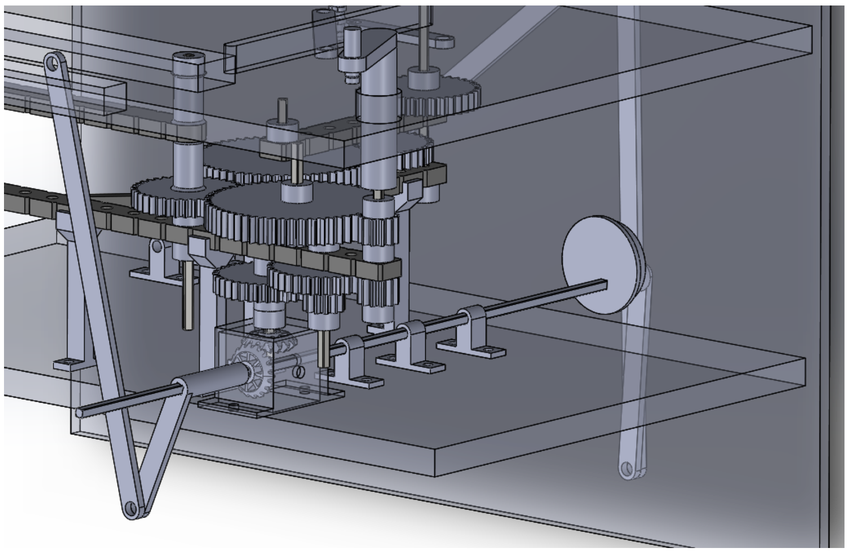


Figure 11: Bevel Gear Motion Transmission

The path towards the bevel gears includes all gear ratios before the bevel gears to decrease backlash on the bevel gears. For simplicity in construction, the ocean waves cam, Bullet Bill slider crank, and Bomb 4-Bar mechanism are all attached to the drive shaft at the end of the bevel gear transmission. A 1:9 (12T:36T, 12T:36T) gear ratio is used from the input crank to bevel gears to decrease the amount of actuations, and for the timing of the bullet bill to cross the finish line.

8.3 Displacement Analysis

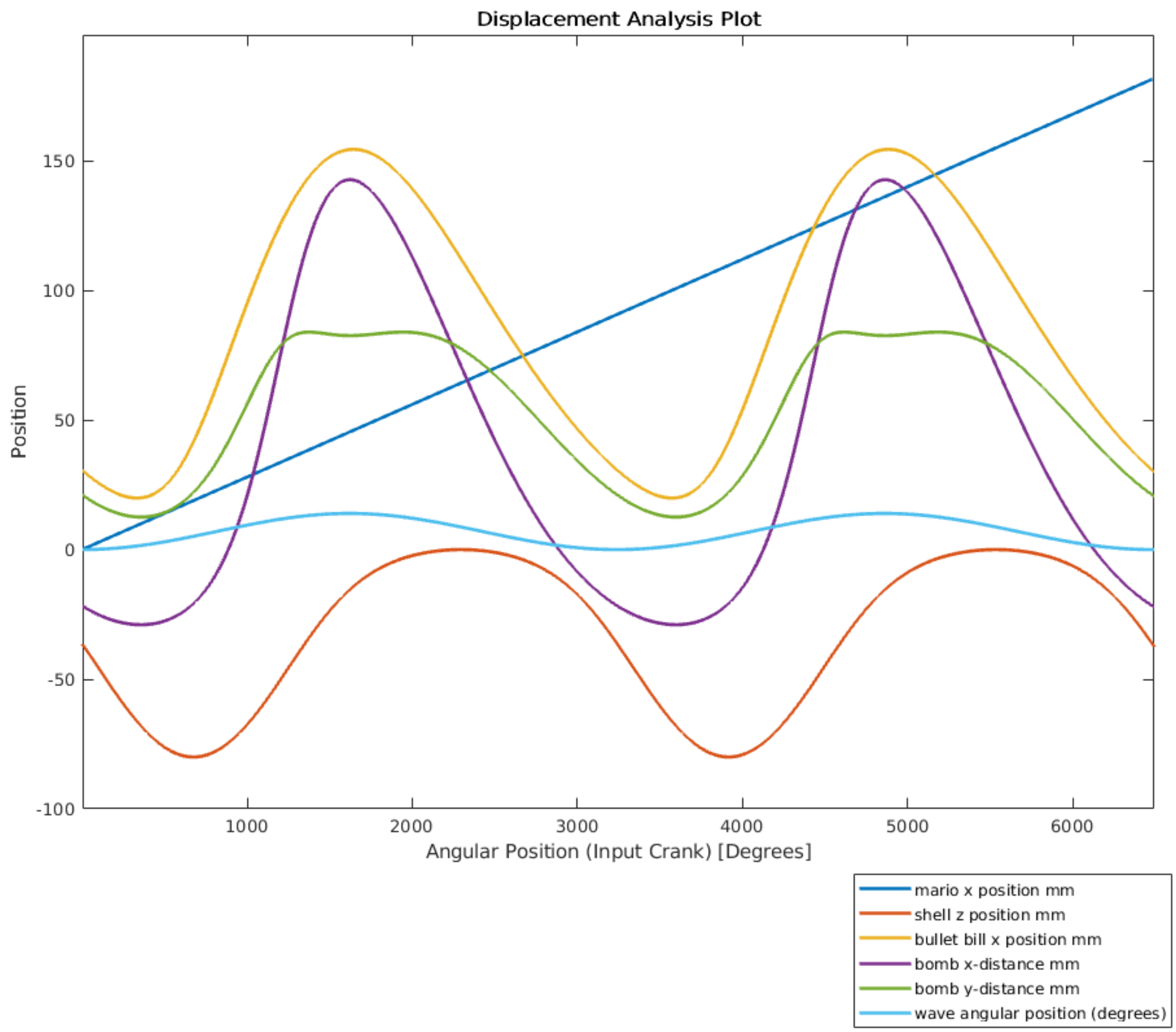


Figure 12: Displacement Analysis Plot

Figure 12 above displays the displacement of each component in our Automaton. The x-axis represents angular position of the input crank which rotates 18 times per Automaton actuation. The motion of the Mario Kart was modelled using a simple ramp function from its start to end position. Using the conventions learned in class, we were able to analyze the displacement of the linkage components. The slider cranks and 4-bar mechanism's displacements were analyzed using loop closure equations (Appendix). Finally, the motion of ocean waves were analyzed using the outputted function from the "Cam PRF" program in MATLAB, then calculating the angle of the wave which is acting as a pivot arm. To calculate the angle: $\Theta = \arcsin((\text{Rise\_of\_cam})/(\text{Distance\_of\_arm\_to\_ancor\_point}))$.

As seen in the plot, the position of the bomb, bullet bill, and ocean wave since they are mounted in the same orientation on the same drive shaft. The shell's position is 90 degrees out of phase from the other mechanisms due to the orientation which the input link was installed to the VEX drive shaft.

This is because the drive shaft is rectangular, meaning that there are only 4 possible orientations of the input link.

9 Testing/Evaluation

9.1 Project Physical Model

Figure 13: Physical Model Overview

Figure 14: Front View of Mechanism

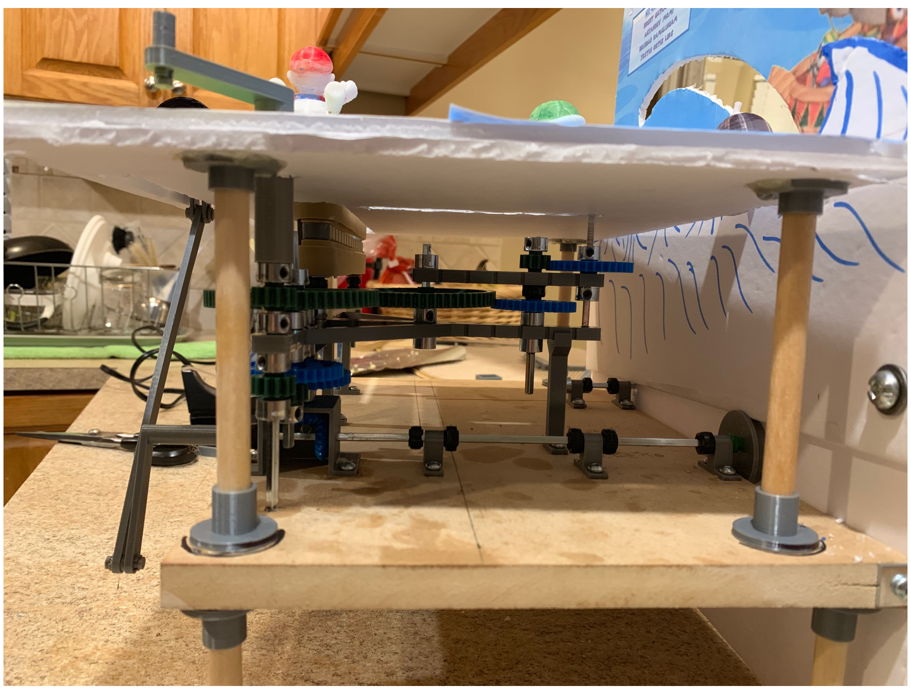


Figure 15: Side View of Mechanism

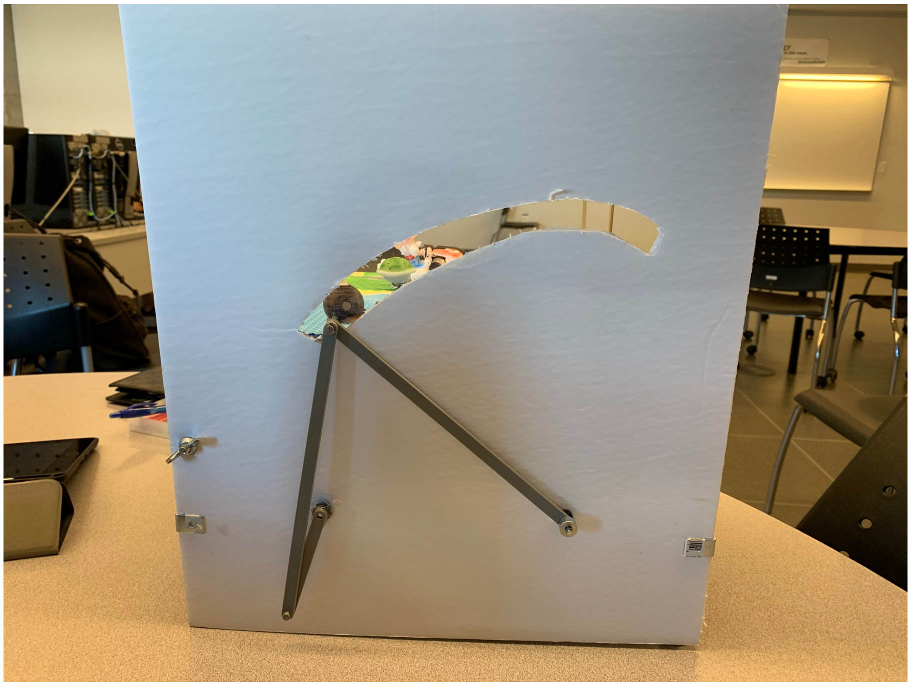


Figure 16: Back View of Mechanism (4-Bar Linkage)

9.2 Video Demonstration

A video demonstration of the physical prototype can be found in the following link:

https://youtu.be/gHvEvZP6KXA

9.3 Testing of Physical System and Implemented Solutions

The list below outlines the problems which were encountered while manufacturing the physical model and solutions which were implemented:

Problems

1. Difficulty of turning the crank (unstable base)
2. Bevel gear misalignment
3. Gears had too much friction when initiating the animation
4. Wave animation slipped too much and had overshoot

Solutions

1. Used mechanical fasteners to ensure a stronger and more stable foundation.
2. Created a gear box housing for the bevel gears to ensure proper meshing and alignment.
3. Added grease to the gears and shafts to smoothen out the entire animation of the system
4. Mechanically fastened wave and cam mechanism to minimize deviations in movement.

10 Reflection on Future Improvements

An area where our system was running into issues was implementing a pulley system for the animation of the Mario go cart. This system was simple to implement, however for the build of the system we found that the elastic band on rotation were not ideal material to hot glue 3d printed components to. The glue would not adhere to the material and made poor contact therefore another rubber band was used on top to hold the printed component. A future improvement to the system would be to use a chain drive system for the pulley in order to remove the unwanted elasticity in the system.

Another improvement to the system add complexity to the system animation by implementing a mechanism to introduce spring actuation to the Mario go cart on impact with the Koopa shell. Introducing a different timing scheme, the story can be animated to have the Koopa shell impact the Mario go cart in while a spring actuation could flip or actuate the go cart off the map which would give a better story to the implemented animations.

11 Recommendations and Conclusion

In this project we were able to implement a automaton which tells the story of a Mario Kart video game simulation. The automaton simulated the Mario cart travelling towards the finish line, while other animated components such as the 'Bullet Bill', 'Koopa shell' and flying bomb were aids in narrating the story of Mario Kart path to the finish line surpassing these impediments. Through analysis methods introduced in class we were able to describe the synthesis of the mechanisms in order to design the system animations required, define the motion flow, and develop a displacement analysis plot. Through the displacement analysis plot we were able to understand the system movement relative to each animated component and evaluate the total displacement movement of the system. The physical model developed initially encountered a few problems as outlined in the sections above and implemented solutions.

A future recommendation for this project is to provide more familiarity with timing of mechanisms in order to evaluate the implemented solution with theoretical values and also drive train solutions for multiple mechanisms.

12 References

1. "Automaton", Encyclopedia Britannica, 1998. (Online).
Available: https://www.britannica.com/technology/automaton. Accessed: 20- Jul- 2019.

13 Appendix

13.1 CAD Design Views

A solidworks assembly file and all component files are included in the compressed folder documents attached to this report.

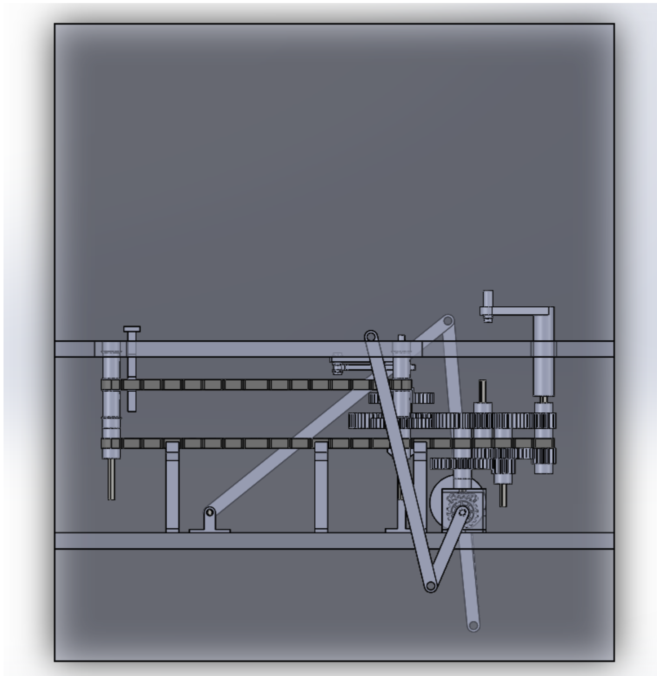


Figure 17: CAD Design Front

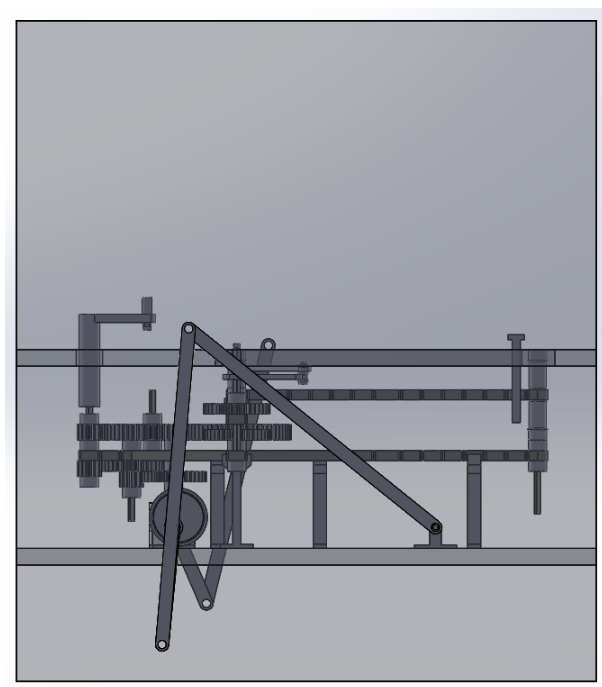


Figure 18: CAD Design Back

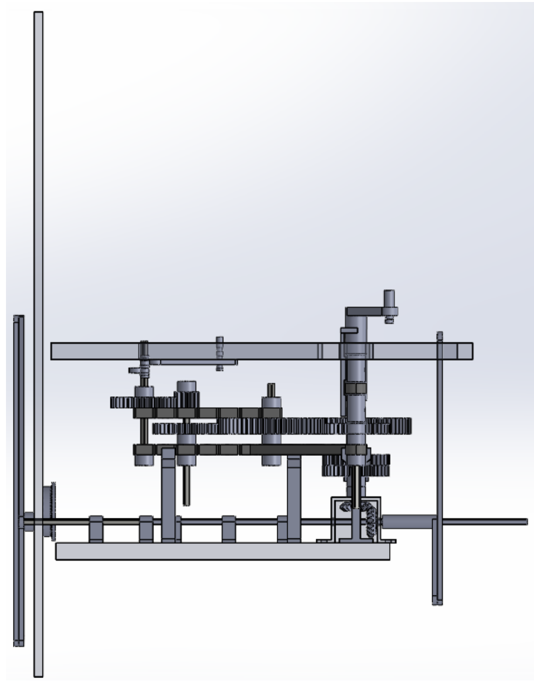


Figure 19: CAD Design Side Left

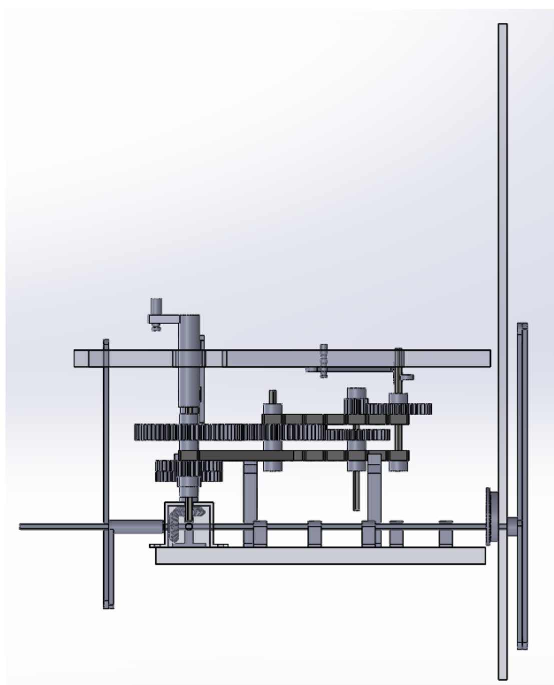
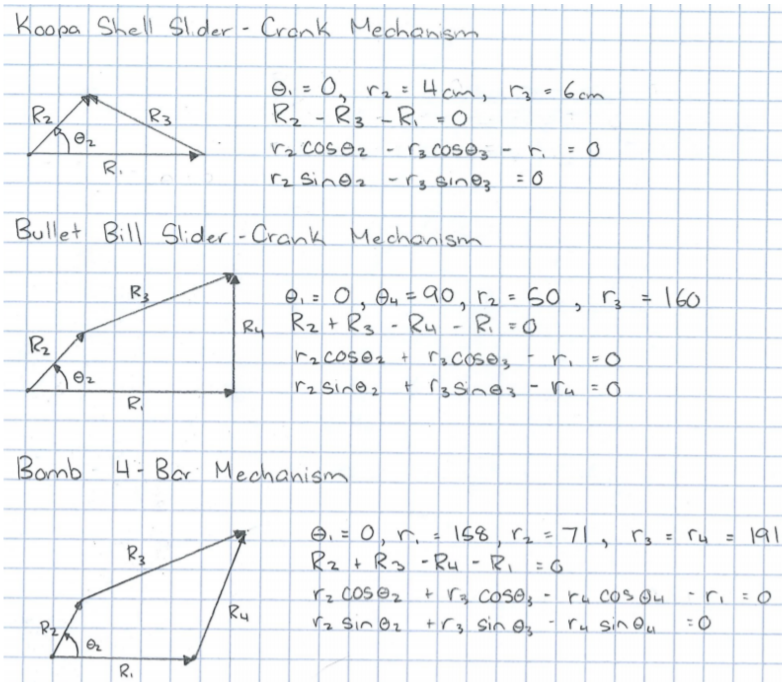


Figure 20: CAD Design Side Right

13.2 Loop Enclosure Equations



13.3 Displacement Plot Code

Matlab code attached as file in the compressed file submission.