Team 4 – Mario Kart Simulation Conceptual Design

Blake Pickett
Computer and Electrical Engineering Department
Tennesse Technological University
Cookeville, TN
bcpickett42@tntech.edu

Tyler Chittum
Computer and Electrical Engineering Department
Tennesse Technological University
Cookeville, TN
thchittum42@tntech.edu

Benjamin Reed
Computer and Electrical Engineering Department
Tennesse Technological University
Cookeville, TN
bdreed43@tntech.edu

Ray Durlin
Computer and Electrical Engineering Department
Tennesse Technological University
Cookeville, TN
rjdurlin42@tntech.edu

Sage Mooneyham
Computer and Electrical Engineering Department
Tennesse Technological University
Cookeville, TN
samooneyha43@tntech.edu

***Abstract*— This report introduces Team 4's Conceptual Design for the Fall 2022 / Spring 2023 Capstone Project. The report begins with an introduction to the problem, followed by the overall objective and scope. Additionally, system description, along with a block diagram and details, background information, constraints, and standards are discussed. The report also describes possible solutions and addresses measures of success, unknowns/obstacles, readily available solutions, safety concerns, and broader implications, ethics, and responsibility associated with the solution. Finally, Team 4's resources for completing the project are described, including the personnel, components, funding, and timeline.**

Keywords*— *Capstone Design, gaming, exercise, sensors, magnetic, electromagnetic, engineering, resistance, trail

I. INTRODUCTION

With obesity rates on the rise in the United States, the Mario Kart Bike offers a win-win scenario for gaming enthusiasts in that gamers can participate in physical activity while playing Mario Kart. "According to the Department of Health and Human Services and the CDC, 42.4% of U.S. adults are currently obese. That is up substantially from the 30.5% measured in 2000" [1]. The intent for designing and developing this exercise/gaming innovation is to inspire gamers to participate in physical activity, thereby improving their overall health. With a staggering 66% of Americans playing video games, the Mario Kart Bike could have a significant impact on the general health of society simply by adding a little physical activity to the day-to-day activities of the gaming population [2]. Exercise bikes have proven to be "an efficient and effective way to burn calories and body fat while strengthening your heart, lungs, and muscles" [3]; therefore, merging them with video games is expected to be an effective method to improve the well-being and longevity of the video game playing population.

The objective of Capstone Design Project Team 4's project is to further enhance the riding experience offered by the existing design of the Mario Kart Bike by adding a variable of resistance for two modes of operation: the Mario Kart game simulation and a pre-recorded trail ride simulation. The scope of Team 4's project includes the provision of a new dimension of realism to the Mario Kart Bike. Specifically, Team 4 will capture data from an actual trail in Cookeville, TN, for use in the pre-recorded trail ride simulation. Team 4 will also add a variable of resistance for both modes of operation. Resistance will be added by either improving the existing motor resistance design or by replacing the existing motor with a magnetic resistance device that utilizes eddy currents to affect the amount of force required to pedal the simulation bike. Team 4's solution includes two kits: the Mario Kart kit and the Ride Replay kit.

The Mario Kart Bike Revision 2 design must adhere to a set of "shall statements" or specifications in order to meet the requirements set by the customer, supervisor, and professor. The specifications specific to only the Mario Kart simulation kit include:

- Game event detection
  - Shall consistently trigger a change in resistance in response to the following in-game events: being hit by a shell, using a mushroom, riding offroad, and going over a boost pad

- Resistance shall be reset to the nominal value after the duration of the in-game event has run its course
- Steering
  - Steering mechanism shall be strengthened using metal components

Specifications specific to only the Ride Replay simulation kit include:

- Ride data replay/simulation
  - Shall produce a resistance which is within 10 % of the value calculated by the simulation software, provided that the calculated power does not exceed the maximum power which the dissipative mechanism is capable of dissipating at the current speed.
- Ride recording (for a bike auxiliary to the exercise bike)
  - Shall synchronously record video, barometric pressure, rear wheel speed, and incline angle; record this data to a non-volatile storage medium
- Ride data filtering
  - Shall attenuate frequencies above 1 Hz by at least 80 dB
- Elevation
  - Rider elevation shall be recorded while rider is recording bike

Specifications that are relevant to both the Mario Kart and Ride Replay kits include:

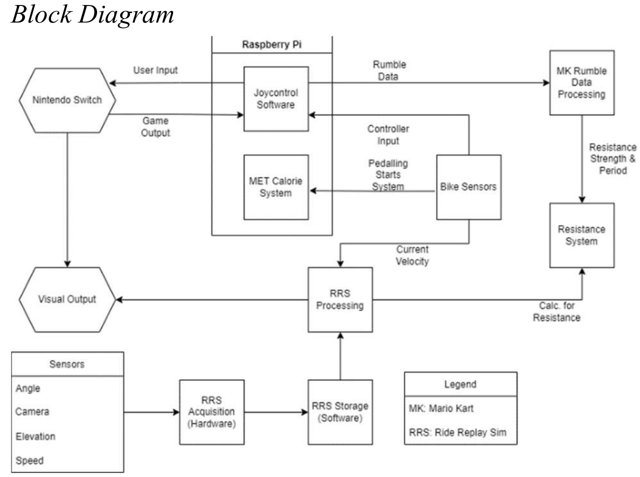
- Main controller board
  - Shall not crash or overheat under normal operating conditions at or near room temperature (70 ± 5 °F)
- Resistance system
  - Shall not surpass 30 V
  - Shall contain at least 85 distinct resistance states
- Speed sensor
  - Shall update the controller with at most 40 mms latency
- Wireless communication
  - Shall provide a latency of at most 40 ms for data transmission between the sensors and main controller board

In addition to adherence to the above mentioned "shall statements," constraints must be identified and addressed to successfully complete the Mario Kart Bike Revision 2. The customer requested that Team 4's design enable easy installation of components such as a phone holder to be used to hold a phone on a bike for gathering data on the route to be replayed or to enable the users to see themselves play Mario Kart in the game. Additionally, Team 4's professor set a hard deadline of two semesters for the completion of the Mario Kart Bike Revision 2, and he limited the budget to $1,000. Ethical considerations, such as possible copyright infringement, will likely prevent the Mario Kart Bike Revision 2 from being commercialized. However, if the Mario Kart Bike can be commercialized, the Revision 2 design must be minimalized and converted to wireless communication, and the motor system used as a source of resistance must be improved to mitigate its safety issues. The voltage supplied by the motor system can be no greater than 30 volts, which is generally considered an upper limit. Team 4's Mario Kart Bike Revision 2 design must follow all related engineering and safety standards, such as those set forth by the Institute of Electrical and Electronics Engineers (IEEE) and the Occupational Safety and Health Administration (OSHA). Additional constraints include the use of physics engine creation or implementation to calculate precise, dynamic resistance. A minimum of 85 resistance states will be used to measure the validity of the dynamic resistance system.

The balance of this Conceptual Design Report outlines Team 4's basic plan for adding resistance to the existing Mario Kart bike design and providing an interactive simulated bike on a trail in Cookeville. By replicating the effects of riding an actual trail in Cookeville, residents and alumni can recall a trail once traveled. The following sections include a system description with a block diagram and details, background, constraints, and standards, as well as solutions with measures of success, unknowns, obstacles, and safety concerns, as well as already available solutions. Additionally, resources are defined, including team members, components, project budget, and timeline.

II. System Description

A. Block Diagram



B. Functional Block Detail

1. *Nintendo Switch:* this is the video game console which the JoyControl software controls for Mario Kart Bike operation. The first output of this block is the rumble data, which is the data that initiates vibration in a video game controller. This data will be transmitted over Bluetooth, which is the wireless communication protocol chosen by Nintendo to interface with peripherals. Different in-game events have different rumble states associated with them, and different functionalities are planned to occur in

response to different rumble states. Specifically, the resistance faced by the rider is planned to increase when an event occurs which impedes the in-game character's go-kart, and to decrease when the in-game character activates a boost. The second output is digital video which will be transmitted through a HDMI cable to a connected TV screen.

2. *Joycontrol Software:* This software is the code that manages Bluetooth communications with the Nintendo Switch, allowing the bike to act as a controller. It was originally created by GitHub user mart1nro and was modified by the Revision 1 team to better meet their needs. The bike sensors' interactions with Joycontrol were specified by the previous team. Slight modifications will be made regarding the steering code to increase steering fidelity. The resistance data obtained by Joycontrol through communication with the Nintendo Switch is to be sent to the Mario Kart Rumble Data Processing subsystem.
3. *Bike Sensors:* this block describes all bike-mounted sensors. These sensors will sense the speed of the back wheel of the exercise bike, as well as the angle of the bike headset. This data will be transmitted wirelessly to the relevant device (either the Raspberry Pi, for the Mario Kart Bike, or the RRS Processing block, for the Ride Replay). Note that the steering input is not used for the RRS.
4. *MET Calorie System:* This system was originally developed by Revision 1's team. Using attributes input by the user, the MET system tracks how many calories the user burns over time. This aspect of the system will be untouched. However, to attempt to combat the potential of addiction with our bike, we will also be implementing a pop-up that occurs every hour to inform the user that it is advisable to take a break. This will be implemented using the same GUI package currently in use for the MET system.
5. *Mario Kart Rumble Data Processing:* The goal for the resistance system regarding Mario Kart gameplay is to produce resistance depending on game related events. Such events include driving off track and being hit by an item. Due to legal interference, the occurrence of in-game events can only be acknowledged by outputs provided by the game itself rather than directly through the game code. The only output that meets the criteria of being sent to the user by the game regarding in-game events is controller rumble data. The Mario Kart Rumble Data Processing subsystem consists of three sections: acquisition, storage, and instruction. Rumble data is obtained by the Joycontrol software from the Nintendo Switch. Rumble acquisition can be completed by accessing that data and sending the current state to the storage section. The storage section also includes retrieval of data. The retrieval of data must be as fast as possible to minimize controller latency. Therefore, storage and retrieval will be accomplished using the hash map data structure. Hash maps have a worst case time complexity of O(n) and an average time complexity of O(1), making hash maps one of the overall fastest data structures to implement. Finally, instruction refers to the values retrieved from the hash maps, specifically resistance magnitude and duration, that are sent to the resistance system.
6. *Resistance System:* this block will produce a resistance which the rider must pedal against using an eddy-current-based system. The resistance will be set by the software block relevant to the current mode of operation (RRS Processing or MK Rumble Data Processing) and a linear actuator will be used to modulate the distance of a permanent magnet from the surface of a flywheel.
7. *Sensors:* this block describes the sensors required to gather ride data for the RRS Acquisition (Hardware) block. These sensors are used to detect the incline of the surface on which a bike travels, the speed of the bike, and the elevation (via a barometric sensor), and a video of the ride.
8. *RRS Acquisition (Hardware):* this block describes the hardware device used to capture ride data for use by the RRS. This device should be capable of processing video, storing data to non-volatile memory, and sampling data from external sensors.
9. *Ride Replay Simulation Storage:* Similar to the storage section of the Mario Kart Rumble Data Processing subsystem, the data collected during the acquisitional phase must be stored. The storage system for the simulation will have an ever-growing volume of data to be managed while also not requiring the same execution speed that the Mario Kart Rumble Data Processing subsystem requires. Game data will be stored in a 256 GB hard drive that will contain as many tracks as possible. This will be retrieved using an algorithm implemented into the microcontroller that will be used for simulation processing. Whether this processor is the Raspberry Pi already in use or a separate processor is presently unknown.
10. *Ride Replay Simulation Processing:* This subsystem is the most technically intensive part of the system as it retrieves game data, distributes outputs in the form of resistance values and video displays, obtains user speed inputs, and various other processing components required to operate the simulation. As stated previously, the exact processor that will be utilized is still unknown. However, the processor will be programmed to track the user's present speed. The video display will simulate an increase or decrease in speed by increasing or decreasing the frame rate of the video when the user is faster or slower, respectively, regarding the user's speed at that moment when the ride was recorded. The processor

will constantly be updating and sending resistance values to the resistance system depending on user momentum and the gravitational force exerted on the rider at the current incline angle. Momentum will also be considered when determining the progression of the video playback.

III. Conceptual Design Solutions

A. *Conceptual Design Fit*

The conceptual design document created is intended to be used as an analytical document that aims to identify and understand critical design aspects within the project. A critical component for project success matrix was developed to identify the critical elements of the project constraints. A full matrix is shown in Table 2 in the appendix. Table 1 below represents the order of critical tasks. The four criteria of each constraint are complexity, project impact, availability, and cost. Each criterion is weighted, and justification for weight of each criterion is defined in Table 2.

Table 1. Priority Ranking of Critical Components.

Constraint	**Ranking Based on Matrix Score**
Resistance system	1
Ride recording (for a bike auxiliary to the exercise bike)	2
Speed sensor	3
Wireless communication	4
Ride data replay/simulation Accuracy	5
Ride data filtering	6
Main controller board	7
Steering	8
Game Event Detection	9
Elevation	10

B. *Constraint Compliance & Validation*

Below describes the analytical method employed to validate the constraint complies within specifications.

Mario Kart Simulator Specific

- *Game event detection:* Verification that all data transfers during acquisition, storage, and instruction sent and received are as commanded.
- *Steering:* Verification of steering mechanism is metal in material and secured to Mario Kart simulation bike.

Ride Replay Simulator Specific

- *Ride data replay/simulation:* Validate distribution outputs in the form of resistance values and video display corresponds accurately based on recorded data. Resistance must be within 10% of the value calculated by the simulation software.
- *Ride recording:* Validation of data recorded from bike sensors are accessible and readable on data storage device.
- *Ride data filtering:* Verification of frequency attenuation at 80dB above 1 Hz.
- *Elevation:* Verify accuracy of recorded elevation with 5% of actual elevation.

Both Mario Kart & Ride Replay Simulator

- *Main control board:* Validate that there are no error messages or operational malfunctions of the main control board 70 ± 5 °F.
- *Resistance system:* Validate that the resistance system receives all 85 resistance states and adjusts resistance accurately. Measure system voltage to be less than 30 V.
- *Speed sensor:* Verification of 40 ms latency to be measured at the main control board.
- *Wireless communication:* Validate all sensors are wireless. Verify 40 ms latency to be measured at the main control board.

C. *Timeline*

The Gantt chart task data for the project can be seen below in Figure 1. This figure reflects the tasks from the beginning of the project until 10/16/2020. An entire Gantt chart diagram is in the appendix section of the report as Figure 2. The next stage of the timeline is to complete the informal presentation/ design review, which is indicated as a milestone on the Gantt chart, as this is a significant step for approval and feedback of design. After presentation/ design review, the next stage of the project is to complete the final conceptual design and planning report. The conceptual design and planning section is separated into the critical components necessary to complete the detail design and analytical verification. Dividing up team resources will allow for better and more thorough research of each component.

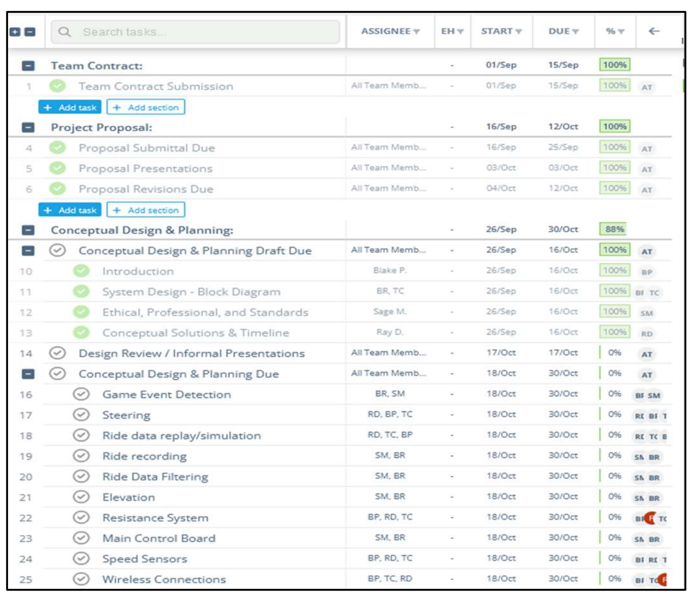


Figure 1. Gantt Chart Task Data from Beginning to 10/16/22.

IV. Ethical, Professional, & Standards Considerations

A. Ethical Considerations

One ethical consideration involves the Ride Replay mode of the Mario Kart Bike. In gathering data (riding a route) for this mode, the user will be recording whatever is in front of their bike during the route. While recording the ride, there lies the chance that the user may record something that they shouldn't be. This could range from a variety of things, from filming individuals inside their homes, to filming customers inside a building with a no-photo policy, to even something graphic or illegal. While the chances of this happening are most likely slim, they still need to be considered, so as not to impose on the privacy and safety of others. Because of this, a constraint on product testing is needed: all testing of the Ride Replay mode will be done in public areas where recording is allowed. By testing in these specific areas, we can be sure that the privacy of others is protected. If this bike were to be commercialized, implementation of a system to blur out faces detected would be used, along with a report function that would flag tracks that potentially need to be deleted. A team dedicated to reviewing these flags would be created.

Another ethical consideration involves the trend of video game addiction in the world, with 3-4% of gamers being addicted [5]. Theoretically, the Mario Kart Bike could cause users to spend even more time indoors, as well as contribute to the video game addiction trend. To combat this, a system will be implemented that displays a message every 2 hours, telling the user that they may want to take a break. This message will also display the total time the user has been using the bike. While this isn't the most effective way to fight the video game addiction problem, it will at least let the user think about how long they've been playing.

B. Professional Considerations

A professional consideration is necessary when thinking about commercialization of the Mario Kart Bike. It is important that throughout the design process, the copyright laws provided to Nintendo by the law are not infringed upon [4]. These laws provide Nintendo with exclusive rights to its products, these including anti-piracy of Nintendo products, use of circumvention devices, and intellectual property. Intellectual property is any innovation, commercial or artistic, or any unique name, symbol, design, or logo used commercially. Nintendo has a lot of intellectual property, including Donkey Kong, The Legend of Zelda, and Mario Kart. These laws provide two constraints for the design process. First, while we plan to redesign the bike to be in a more commercialized, clean form, actual commercialization of the bike is not legal as of now. This is mainly due to the naming of the bike, as Mario Kart is trademarked intellectual property owned by Nintendo. Second, Nintendo games are also protected by copyright laws, and Nintendo does not allow modification, or even viewing of game code. This is an issue because game data must be gathered to properly implement the dynamic resistance system in Mario Kart. To solve this, gathering of game data will be accomplished through rumble state data acquisition.

C. Standards

IEEE 1309 Standard for Calibration of Electromagnetic Field Sensors and Probes, Excluding Antennas, from 9 kHz to 40 GHz: In this standard, orientation of electromagnetic field sensors and their calibration methods are discussed. Since Team 4 will be implementing an electromagnetic resistance device that utilizes eddy currents, we will want to be able to precisely measure associated fields. This standard goes over three main methods for field sensor calibration; Team 4 will be using method B. This method states that the unit under calibration is placed in a calculated reference field based on the geometry of the field source and the field source measured input parameters.

C95.1 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz: In this standard, various safety levels are given for magnetic and electric field magnitudes. These limits change based on the frequency of the waves, and what body part is under the field. We will be constrained by these limits to follow safety standards.

1926.300b.2 - OSHA Standard for Guarding from Rotating or Moving Parts of Equipment: These standard states that belts, gears, shafts, pulleys, sprockets, spindles, drums, fly wheels, chains, or other reciprocating, rotating, or moving parts of equipment shall be guarded if such parts are exposed to contact by employees (users in this case) or otherwise create a hazard. We will be using a fly wheel for our Mario Kart Bike, so we need to make sure that it is guarded if it could potentially create a hazard for the user.

1910.137 OSHA Standard for Electrical Protective Equipment: This standard goes over various electrical protective equipment standards, and specifically tests to determine the effectiveness of protective equipment. This is a constraint, as Team 4 shall wear necessary protective equipment while working with electricity and perform effectiveness tests on each article of equipment.

1910.133a OSHA Standard for Eye and Face Protection: These standard states that the employer shall ensure that each affected employee (member of Team 4 in this case) uses appropriate eye or face protection when exposed to eye or face hazards from flying particles, molten metal, liquid chemicals, acids or caustic liquids, chemical gases or vapors, or potentially injurious light radiation. This will be a necessary constraint if, and when soldering is performed.

REFERENCES

[1] "As us obesity epidemic grows, new study shows who is gaining weight over the last decade," *ScienceDaily*, 23-Jun-2022. [Online]. Available: https://www.sciencedaily.com/releases/2022/06/220623140610.htm.

[2] D. Takahashi, "ESA: 66% of Americans play games and 88% of players say gaming relieves stress," VentureBeat, 07-Jun-2022. [Online]. Available: https://venturebeat.com/games/esa-65-of-americans-play-games-and-88-of-players-say-games-relieve-stress/.

[3] J. Manlove, "7 great benefits of a stationary bike workout," Penn State PRO Wellness, 25-May-2021. [Online]. Available: https://prowellness.childrens.pennstatehealth.org/7-great-benefits-of-a-stationary-bike-workout/.

[4] "Intellectual property & piracy FAQ," Nintendo Support: Intellectual Property & Piracy FAQ. [Online]. Available: https://en-americas-support.nintendo.com/app/answers/detail/a_id/55888/kw/intellectual%20property. [Accessed: 24-Sep-2022].

[5] Video game industry statistics, Trends and data in 2022. (2022, April 29). Retrieved October 13, 2022, from https://gamefid.com/video-game-statistics

APPENDIX

Table 2. Critical Component Decision Matrix.

Critical Component Decision Matrix

		Weight	1	Weight	3	Weight	2	Weight	2	
Constraint	**System Used On**	**Complexity**	**Score**	**Project Impact**	**Score**	**Cost**	**Score**	**Availability**	**Score**	**Total Score**
Resistance system	Both	2	2	3	9	3	6	3	6	23
Ride recording (for a bike auxiliary to the exercise bike)	Ride Replay Sim	1	1	3	9	3	6	3	6	22
Speed sensor	Both	1	1	3	9	2	4	2	4	18
Wireless communication	Both	2	2	2	6	3	6	2	4	18
Ride data replay/simulation Accuracy	Ride Replay Sim	3	3	3	9	1	2	1	2	16
Ride data filtering	Ride Replay Sim	2	2	2	6	2	4	2	4	16
Main controller board	Both	2	2	3	9	1	2	1	2	15
Steering	Mario Kart Sim	1	1	1	3	2	4	1	2	10
Game Event Detection	Mario Kart Sim	2	2	1	3	1	2	1	2	9
Elevation	Ride Replay Sim	1	1	1	3	1	2	1	2	8

Priority	**Level**
Low	1
Medium	2
High	3

Criteria	**Weight**	**Weight Priority Justification**
Complexity	1	Low: There is sufficient time in project for research and analytical testing
Project Impact	3	High: Single component failure could lead to complete project failure
Cost	2	Moderate: The budget is very small for this project
Availability	2	Moderate: Order process may be lengthy; Without a specific component a constraint may not met

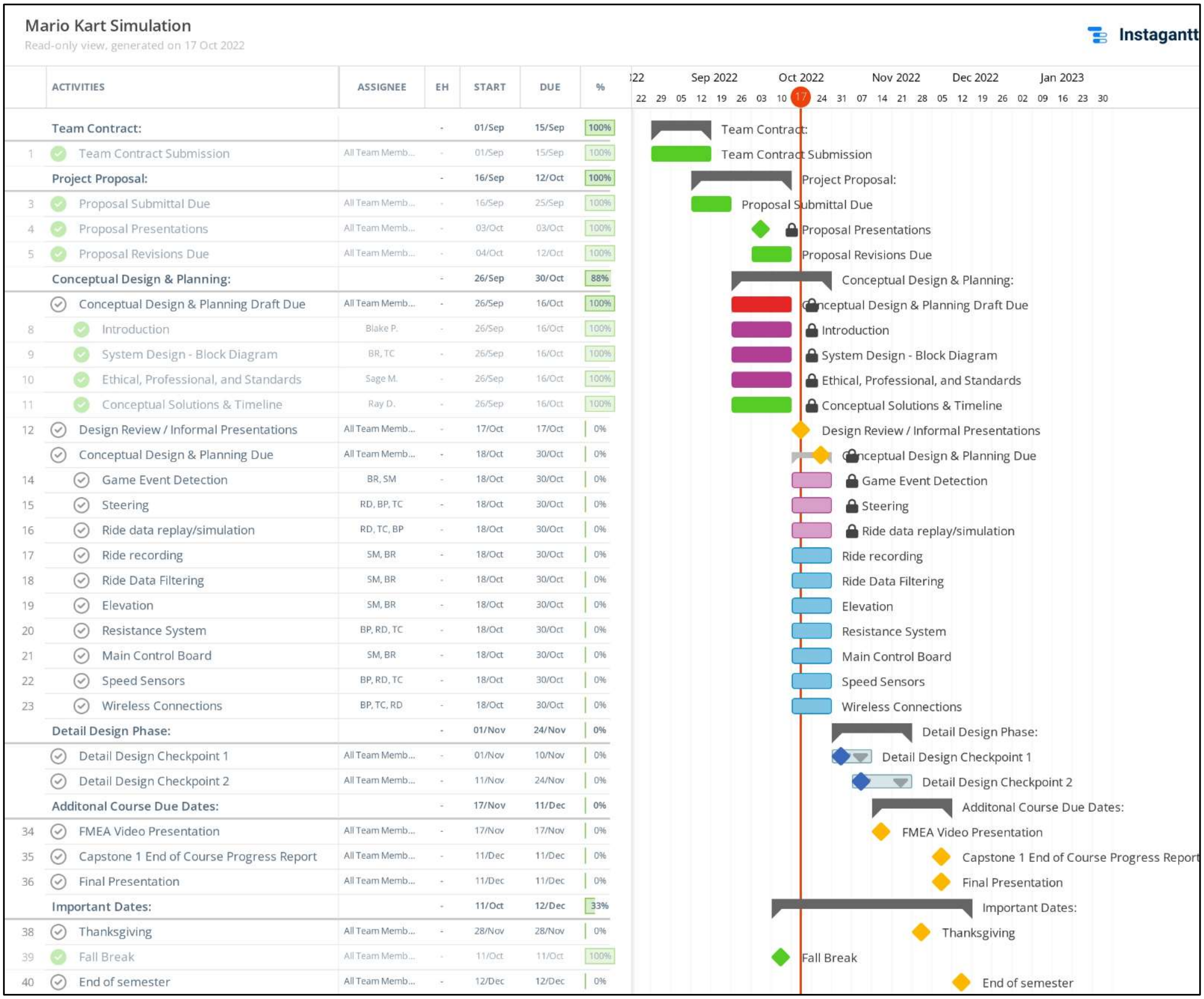


Figure 2. Complete Gantt Chart of Mario Kart Simulator Project.