Team 5 - Mario Kart Bike

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***Abstract*—**The purpose of this proposal is to introduce Team 5's idea for the Fall 2023 / Spring 2024 Capstone Project. The document begins with an overview of the identified problems, followed by a clear formulation of the issues at hand. Moreover, it dives into the necessary specifications, background context, and constraints relevant to the project's scope. The proposal further outlines potential solutions and highlights criteria for assessing success, as well as potential obstacles. Additionally, readily available solutions and concepts are discussed, alongside a consideration of the broader ethical and societal implications. Lastly, Team 5 provides an overview of the resources available and needed to complete the project, a timeline of due dates and expectations of the project.

Keywords *— Exercise bike, Mario Kart, variable resistance, feedback, vibration, heart rate, work, Capstone Design, gaming, exercise, sensors, magnetic, electromagnetic, engineering, resistance, trail*

I. INTRODUCTION

From dodging shells to riding up mountain trails, Team 5 proposes to expand the idea proposed by previous groups. The concept for the Mario Kart Bike produced and improved by the previous Capstone Project teams provided riders with an interactive Mario Kart bike ride and ground works for trail recording. These teams provided an experience that allowed the user to exercise while providing an escape from the real world with the Mario Kart world. The objective of Team 5's project is to expand upon the riding experience by reworking the resistance and feedback system made by the previous team. Team 5 proposes to continue the system to capture data from trails in the real world for use in the pre-recorded trail ride simulation. Our team would like to implement a rumble system around the bike, to provide a new dimension of realism. The initial design set out to create an enjoyable workout environment which it accomplished. Physical activity can reduce risk of chronic conditions like obesity, type 2 diabetes, heart disease, depression, anxiety, and dementia [1]. The intent for designing and developing this exercise/gaming innovation is to inspire gamers to participate in physical activity, gaining the previously mentioned benefits. With an enormous 66%

of Americans playing video games, the Mario Kart Bike combines the commonly held hobby with much needed exercise [2].

The Mario Kart series itself is the best selling racing game series of all time with 173 million copies sold[3]. 55 million of these sales are for the newest game Mario Kart 8 Deluxe for the Nintendo Switch. With this being the most popular and most liked racing game, what better game to use than Mario Kart. Many users who have played Mario Kart may be looking for a new way to experience this game. With the addition of resistance and feedback to the exercise bike, the user will get the experience that they are actually in the game on the Mario Kart bike, slowing down when they slow down and speeding up when they speed up. An example of this would be whenever the player is hit by a red shell, their Mario Kart bike will slow down and the resistance on the physical bike will increase. Also, if the player were to use a red mushroom, they would speed up in the game and the bike resistance would decrease for the user making it easier for them to pedal.

Our proposal will rework and improve upon the current iteration of the variable resistance system along with providing an expansion of the feedback system and trail recording system implemented by the previous group. The feedback system would create a more immersive experience, allowing for recording and replication of trails that will provide users with a sense of familiarity. In the following sections, our team will describe in detail the specifications, constraints, and background behind these systems. This proposal will highlight all the different skills and experience that Team 5's members possess. This will also display our members' teamwork and time management capabilities.

II. FORMULATING THE PROBLEM

A. Objective

Team 5's objective is to finalize the Mario Kart Exercise Bike worked on by the previous capstone groups. To do this Team 5 will be redesigning the motor/resistance system, improving the calorie calculation, and improving the feedback system used on the previous iteration of the bike. Additionally Team 5 will be adding an exterior mold to house the exposed wiring and components, rumbling to the force feedback system, and implementing the outdoor recording system.

B. Specifications

Team 5's project is focused on improving the previous capstone team's designs and adding a couple systems. Table I outlines Team 5's specifications of what the system implementations and improvements shall and shall not have.

TABLE I
MARIO KART BIKE SPECIFICATIONS

Specifications for Mario Kart Bike	
System	**Specification**
Rumble system	Shall not cause the rider discomfort or motion sickness while riding the bike. Shall minimize the delay between the rumble system and the actual in-game event.
Heart Rate Monitor	Shall provide a accurate measurement within 10% of calories burned during ride
Work Monitor	Shall keep the error between measured

	and actual work completed at or below 10%
Ride Replay system	Shall maintain a smooth visual appeal at or above 720p.
Revised Resistance System	Shall provide a safe and variable system to provide adversity to the rider. Shall not cause unintended vibration to the rider.

C. Background

The first iteration of the Mario Kart Bike was designed to integrate physical exercise in tandem with playing video games in order to promote health and fitness to a new demographic. This first iteration achieved its overarching goal but was improved upon by the second revision. The second iteration of the Mario Kart Bike sought out to improve the dynamic resistance system, provide a way to collect user health data, and to add the Ride Replay system. The second iteration added a solenoid valve and an aluminum disk to the back wheel of the bike to make the resistance system more variable and safe for the user and recorded the power expended overtime to estimate calories burned. The team designed a kit from scratch to attach to a bike that can record data from an outdoor ride to recreate the corresponding ride on the Mario Kart Bike. Looking at the previous iteration of the bike the bulky motor system provides an unsightly and potentially unsafe environment for the rider. The aluminum disk can potentially wobble creating unnecessary shaking on the bike which could cause health concerns for the rider. The calorie calculation system does work but it is a broad approximation of the energy expended by the user and not entirely accurate since different users will have different levels of physical exertion. The ride replay system did work properly but was damaged during testing and needs to be repaired and officially implemented into the project.

D. Constraints

Team 5's time constraint is two semesters (8 months) with milestone deadlines in between. The budget of the project is $800. The heart rate sensor needs to be non intrusive and our overall size of the motor system needs to be reduced. Team 5's rumble system needs to be as accurate to the game without causing health issues to the user. The bike needs to meet all safety constraints set by any and all governing bodies related to the systems in place, outlined in the 'Standards' section. Team 5 values safety of the user above any constraint set forth for the project.

E. Standards

Mechanics

- 1926.300b.2 - OSHA Standard for Guarding from Rotating or Moving Parts of Equipment
- ASTM F1250-13 Standard Specification for Stationary Upright and Recumbent Exercise Bicycles and Upper Body Ergometers

Electronics

- 1926.404b OSHA Standard for Wiring Design and Protection
- 1910.137 OSHA Standard for Electrical Protective Equipment
- IEC/IEEE 62209-1528:2020 human exposure to radio frequency fields from hand-held devices
- Our device will comply with all applicable regulations set within Title 47 Part 15 of the Code of Federal Regulations.

Medical

- CFR Section: 21 CFR §870.2300
- FDA 510(k) Clearance. a premarket submission made to FDA to demonstrate that the device to be marketed is as safe and effective,
- IEC 60601-2-47:2012 requirements for the basic safety and essential performance of ambulatory electrocardiographic systems

III. SOLUTIONS

A. Measures of Success

Our first measure of success is keeping the error between measured and actual calories burned at or below 10%. Furthermore, the implemented system shall not be intrusive to the user. Our second measure of success is keeping the error between measured and actual work done at or below 10%. Our third measure of success is minimizing the delay for our rumble system integration for Mario Kart gameplay. The rumble system output shall also stay at comfortable levels that allow for a smooth gaming experience. Our fourth measure of success is keeping the resolution of the ride replay system at or above 720p and maintaining a smooth visual appeal.

B. Unknowns, Obstacles, and Safety Concerns

1. *Data Collection for Rumble Effects:* As a result of copyright regulations associated with Nintendo, the team is restricted in obtaining access to the game code. Therefore, actions related to gameplay events, including the system's variable resistance to in-game occurrences, must be triggered through controller inputs from the game itself. These inputs are limited to just the utilization of Nintendo's "HD Rumble" found in each JoyCon controller. These rumbles contain a set of bytes that the controller utilizes to initiate vibrations with varying frequencies, durations, and intensities. During the development of Revision 1, the team briefly contemplated using rumble states; however, due to time constraints, they opted not to implement that system. With the limited documentation available from Nintendo and little feedback coming from the Nintendo Switch to the controller, this may be a challenging task to implement. The only way to determine whether rumble states can be accessed and put to use is by examining the JoyCon code.
2. *Ride Replay System Identity Privacy:* There is a concern about recording non-users during a ride, and protecting the privacy of other bystanders that may be on the recorded ride. An unknown is the legality of when censorship is needed or not. A possible solution to this problem is to use an AI to blur or crop while recording a ride for the sake of privacy.
3. *Frames per Second: An unknown* variable is which fps value would be sufficient for smooth playthrough.
4. Protective Covering Fire Hazard: In an attempt to not only protect users from exposure to possible electrical hazards, but also provide a more sleek exterior to the bike, we are adding a protective covering. An effort needs to be made to ensure minimization of fire hazards in the shell. The protective covering must also not hinder users from their ride experience.

C. Already Available Solutions

Below are some examples of exercise bikes being used as game controllers or similar. Note that, hobbyist solutions refer to those solutions which are not available for public use or purchase in any capacity beyond an idea.

Commercial solutions:

- RealRyder Hong Kong Bikes at Pure Fitness [11] acts as a steering input with which to play Mario Kart. Lacks the ability to modulate the game input based on pedaling speed or apply resistance based on in-game events, which are features Team 4 wishes to implement. The only associated cost for the end user is a gym membership at Pure Fitness Gym in Hong Kong.
- Wii Cyberbike Magnetic Edition [12] A Wii controller is meant to control Cyberbike using speed and steering data. The resistance is adjustable; however, it is not in any way related to the game. The cost is $199.99.
- Expresso Bikes [13] These exercise bikes are designed to provide a full ride simulation experience, including steering input and computer-controlled variable resistance. The bike includes a display and computer with installed simulation games. Said games have notably dated graphics. The cost is not publicly available, though the bike is currently for sale to the public.
- Echelon EX-8s Connect Bike [14] This solution implements variable resistance and ride simulation. It does not include steering, and it is not possible to simulate a user-recorded ride. The cost is $2,299.99.
- Garmin Edge 130 [15] This device is an example of a common bike accessory called a bike computer. The Garmin Edge 130 is capable of recording the user's power output, elevation, speed, calories burned, and a number of other biometric data of interest to bikers. It is capable of measuring all data that we wish to collect with our ride data collection system, aside from optical data. Price: $199.99.

Unisky Bike Trainer Stand [16]

This device is meant to support a mountain bike in a stationary position so it may be used as an exercise bike. It produces resistance by means of a magnet and flywheel system, which is set by the user to
determine the resistance of the bike. This device was previously purchased as part of the original design; though it is currently only being used as a support and flywheel; the portion which modulates the resistance has been removed but is still within inventory. Price: $89.99.

Hobbyist Solutions:

- Xbox Exercise Bike Controller [17] Using an Xbox controller, an Arduino Micro, and a magnetic speed sensor, this YouTube user was able to control the speed and steering of a GTA character riding a bike. Though this represents an entirely different console, the functionality is similar to what Team 4 seeks to implement.
  Exercise Bike PC Game Controller [18] This project allows one to control a PC game using a speed reading from an exercise bike. This is one piece of the functionality Team 5 wishes to implement.
- Nintendo Fit Labo Cart [19] This solution implements a wireless physical manipulator to physically make inputs on the OEM controller, rather than transmitting data directly to the game console. The user input is the speed of the exercise bike flywheel, as well as steering and button inputs on a ring-con (a circular type of controller for the Nintendo Switch). This solution affects a binary a-press, where the button is pressed only after surpassing a certain set speed.

Team 5 Top-Level Solutions:

The following is an outline of key components which have either already been incorporated or that must be incorporated during the design process. [20]

- Resistance element: this component produces a variable mechanical resistance and (if it is capable) to charge a battery or capacitor to power the sensors.
- Speed sensor: this component monitors the speed of the rear wheel of the bike.
- Raspberry Pi: this component acts as the main controller of the device, and interfaces with a touchscreen that provides an HID.
- Wireless module: this component acts to transmit data between devices mounted on the bike and the Raspberry Pi.
- Sensor microcontroller: this component calculates the rear wheel speed and the power dissipation, and relays this to the Raspberry Pi via an attached wireless module.
- Ride data filter: this programmatic component filters noise and undesirably rapid changes in angle and speed out of the recorded data. Typical road noise is broad-spectrum, mostly concentrated on the order-of-magnitude of 1000 Hz [21]. The innate natural frequency of bike tires varies significantly depending on the inflation pressure of the tires, but was well over 1 Hz by two orders of magnitude for both 60 and 120 PSI inflation pressures [7]. Since the tires form the interface between the bike and the ground, frequencies significantly above or below natural frequency of the tires are attenuated, while those near the natural frequency are transferred very effectively. A LPF with a cut-off region starting at 1 Hz could reasonably be expected to produce the desired effect. It would ensure good attenuation of the natural frequency, while allowing fast enough changes to update the resistance according to a change in incline resulting from a hill (at any reasonable speed, a typical hill would take well over 1 s to traverse).
- Playback: this programmatic component handles playback of recorded data and synchronizes the recording frame rate with the current speed of the rider.
- Game event detector: this programmatic component detects events within the Mario Kart game and adjusts the pedaling resistance accordingly.
- Rumble System: This will take feedback from the controller and other sources. It will then send a signal to the vibration actuators found within the seat and handlebars creating a rumble.
- Heart Rate Monitor: This will be implemented within the handlebars of the bike. This data will then be sent to the Arduino to be formatted and sent to the user.

IV. RESOURCES

A. Team Members

The following list is meant to reflect the key proficiencies of each team member.

Ben Ebel:

- Embedded Systems
- C++/C#/C
- Circuit Design/Analysis
- SQL
- Excel
- Microsoft Access Database
- Digital System Design

Caleb Rozenboom:

- Altium PCB Design and Circuit Schematic Creation

- Soldering
- Circuit Design/Testing/Analysis
- AutoCAD
- Electromagnetic Fields
- PLC installation and troubleshooting
- MS Excel
- LTSpice Simulation
- Project Management

Jayden Marcom:

- AutoCAD
- Print Reading
- C++
- Power AutoMate
- Simulink
- Excel
- Circuit Design
- Power Systems
- Arduino
- Solidworks
- Soldering

Jesse Brewster:

- PCB Design and Circuit Schematic Creation within Altium.
- Soldering and Micro-soldering
- AutoCAD
- MS Excel
- PLC design and programming
- Arduino
- 3D Modeling within SolidWorks/Inventor

Utsav Singha:

- Experience in AI coding and implementation
- High level competency with Microsoft Suite of Software
- Electromagnetic Fields
- Experience in Spice circuit simulation
- Soldering
- Project management
- Technical Writing
- Experience in MySQL
- Circuit Design/Testing/Analysis

B. Components and Project Budget

1. Items Needed (Tentative)

- Nintendo Switch with Mario Kart installed (Can buy used)
- Heart Rate Sensor
- Rumblers
- Wireless transmitters
- Neodymium magnet

2. Current Inventory

- Already assembled Mario Kart Bike
- Ride replay system (needs repair)
- Bicycle
- 180 V 1/3 hp PMDC motor
- Raspberry pi and touchscreen display
- Arduino
- LED-based digital tachometer
- Potentiometer
- Wires
- Project box with forced convection
- Frame and flywheel
- Television monitor

3. Budget

Team 5 has budgeted a total of $800 to complete the proposed revisions to the Mario Kart Bike. Table III summarizes the projected costs to be expected of the revisions with examples. This prediction is a rough estimation of the projected cost. It is not possible during this phase of the project to correctly budget for all the materials; however, Team 5 has done their best to estimate accurate costs for our bill of materials. Prices do not include shipping since this is merchant dependent and can range, however, this should not be a major expense.

TABLE II
BILL OF MATERIALS

Bill of Materials		
Material	**Cost (USD)**	**Example**

Nintendo Switch	$270	https://tinyurl.com/59zwp4bv
Mario Kart 8 Deluxe	$40	https://tinyurl.com/5sjrsdpe
Insta-Pulse Heart Rate Bars	$129	https://gophersport.com/insta-pulse-heart-rate-bars
Gopro/Camera	$195	https://tinyurl.com/yc2s3jmj
2 White PLA 3D filament	$40	https://tinyurl.com/mu5a35s6
Shipping and Handling	$50	
Unforeseeable Costs and Repairs	$76	

C. Timeline

This section will outline the timeline of Team 5's due dates and events. These due dates have all been outlined in Table III.

TABLE III
TEAM 5 TIMELINE FOR EVENTS

Timeline for Events	
Item	**Due Date**
Teamwork Contract	August 28th 2023 at 1:00 PM
Minutes Week 1	August 28th 2023 11:59 PM
Minutes Week 2	September 5th 2023 11:59 PM
Minutes Week 3	September 12th 2023 11:59 PM
Project proposal	September 17th 2023 at 11:59 PM
Minutes Week 4	September 19th 2023 11:59 PM
Minutes Week 5	September 25th 2023 11:59 PM
Minutes Week 6	October 2nd 2023 at 11:59 PM
Conceptual Design & Planning Draft	October 4th 2023 at 11:59 PM
Minutes Week 7	October 9th 2023 at 11:59 PM
Detail Design Checkpoint 1	October 15th 2023 ar 11:59 PM
Minutes Week 8	October 16th 2023 at 11:59 PM
Mid-Term Progress Presentation	October 23rd 2023 at 11:59 PM
Minutes Week 9	October 23rd 2023 at 11:59 PM
Minutes Week 10	October 30th 2023 at 11:59 PM
Detail Design Checkpoint 2	November 1st 2023 at 11:59 PM
Minutes Week 11	November 6th 2023 at 11:59 PM
Minutes Week 12	November 13th 2023 at 11:59 PM
Minutes Week 13	November 20th 2023 at 11:59 PM
Minutes Week 14	November 27th 2023 at 11:59 PM
Github Customization & Update	November 29th 2023 at 11:59 PM
Final Presentation	December 8th 2023 at 11:59 PM

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Figure 1. Team 4 Gantt Chart Activities Data.

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