Best Ball

Authors: Seaver Dahlgren, Erik Feldmann, CJ Hess
Affiliation: Electrical and Computer Engineering, Carnegie Mellon University

***Abstract*—A system capable of measuring various putting metrics including the score to provide a golfer with valuable feedback to improve their golf skills and track score among friends playing the game.**

***Index Terms*—Ball, Hole, Putt, Putter, Sensor**

1 INTRODUCTION

Our project seeks to provide golfers with real-time feedback on their putting performance. Through various sensors in the ball, putter, and green, our system can give the golfer feedback on their stroke speed, acceleration, ball spin rate, miss direction, and putt accuracy across various distances.

This project can be utilized by the professional and the novice alike. Our project seeks to provide all levels of golfers the ability to use multi-player mode to not only see their stats, but also keep score during a game of miniature golf with up to 3 players.

Modern golf has access to tools and technologies all based on their swing and bath flight, but the market for putt tracking tools does not seem to be as saturated. With this product, we hope to help golfers practice and receive feedback on their abilities around putting green.

2 USE-CASE REQUIREMENTS

2.1 Real-Time Data

In order to provide our users with metrics during their practice sessions, we will need to provide them with real-time feedback.

2.2 Allow for multiple users

In order to allow our users to play mini golf, our system will require a multiplayer mode.

2.3 Portability

In order to display putting metrics from our system to the user, data will flow through a portable user interface.

2.4 Accuracy

In order to provide our users with accurate metrics, we will need to measure putting phenomena accurately. The system shall detect ball hits with 90 percent accuracy as this will provide a reasonable threshold that will still provide useful feedback.

2.5 Uninterrupted Golf Experience

In order to best simulate a real golf experience for our users, we will require that the hole and putter used in our system match putters and gaps found in real golf.

3 ARCHITECTURE AND/OR PRINCIPLE OF OPERATION

Our system will be composed of six primary components, the ball, the putter, the hole, the start mat, the green, and a web app.

The ball will be a custom golf ball built to include the sensors necessary to gather metrics on the balls path and spin rate.

The putter will be a standard golf putter fitted with sensors to provide the user with feedback about their putting stroke.

The hole will be the size of a standard golf hole and be fitted with sensors to detect when a putt has been made.

The start mat will help to identify and assign players with balls. This process will seamlessly help with multiplayer integration.

The green with be fitted with sensors to measure the distance from the ball to the hole as well as track the ball's position throughout play.

The web app will display the putting metrics to the user and will also display a scoreboard when our users are in multiplayer mode.

4 DESIGN REQUIREMENTS

The design requirements for our system are defined by the use-case requirements.

Our first use case requirement, states that the user should receive real-time metrics about their putting. In order to achieve this, we will require our design to have an end-to-end latency from putt to web app of 5 seconds giving the user reasonably fast feedback on every putt.

Our second use case-requirement mandates that we have a multiplayer mode. Our system will be required to accommodate up to 3 players at the same time. This will include 1 putter shared across players, 3 balls uniquely assigned to each player, and the ability for each player to simultaneously view the web app displaying putting metrics as well as score.

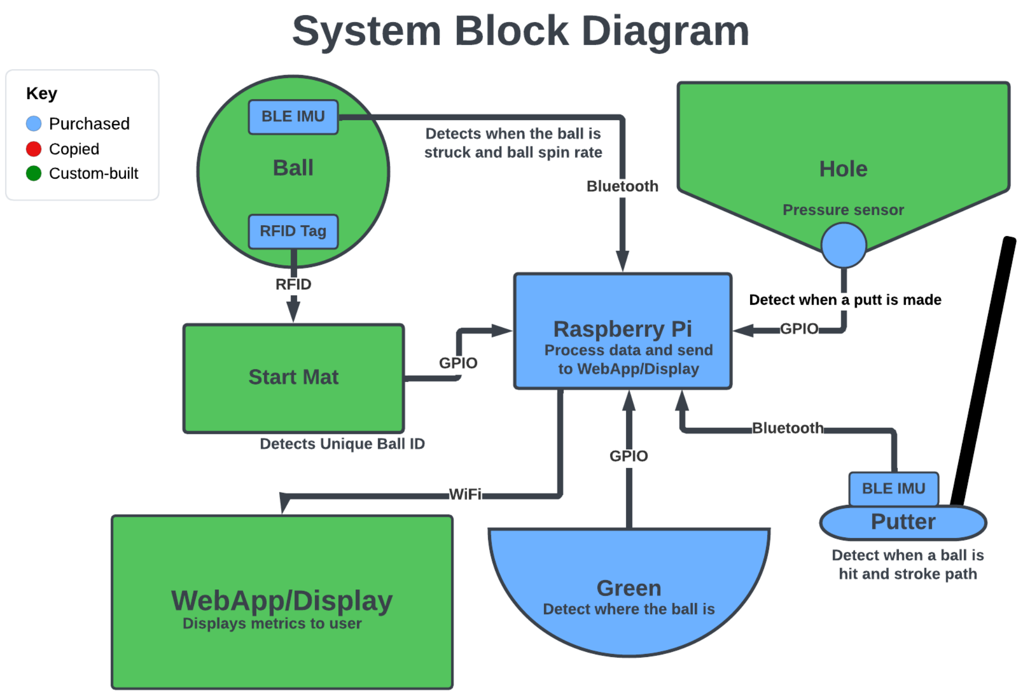


Figure 1: System Block Diagram.

Our third use case requirement deals with the specific metrics displayed to the user. First, our system will accurately measure the distance from the ball to the hole within three centimeters of the true distance. Second, our system will accurately detect when a ball is struck (i.e. a putt) and when a putt is made both with a 95 percent accuracy. Our system will also be required to accurately detect the swing path of the putter labeling it as constant, decelerating through the ball, or accelerating through the ball. We will require our system to correctly label these swing paths with 90 percent accuracy.

Finally, we will require our system to achieve an experience as similar to real golf as possible. To achieve this, our design will incorporate a standard golf putter fitted with sensors, a standard golf hole fitted with sensors, and a custom golf ball fitted with sensors that are close to the size and feel of a real golf ball. We will require our ball to have a diameter between 4.27 centimeters (a normal golf ball) and 6 centimeters to allow for potentially needed room to fit all the sensors. We will also require that the system have a battery life of at least one hour in order for users to enjoy a long practice time. Our putting green will be required to have a length of 3 meters and a width of 1.5 meters.

5 DESIGN TRADE STUDIES

We examined multiple methods to implement this system. Below are some of our rejected implementations for each of our subsystems and the reasoning behind not choosing these implementations. The hole and the webapp are the only subsystem that remains as it was planned from day 1. The starting mat also did not have any iterations, however, it was a newer addition to our system.

5.1 Ball

The ball went through various design iterations until we finalized our implementation. We began with the idea of simply using a golf ball and quickly realised how hard it would be to get any information about the ball without an onboard sensor. We then discussed implanting our IMU in a real golf ball and simply gluing the halves back together. We abandoned this approach for two reasons, first, this would leave the ball unbalanced and not roll properly. Second, the process of opening the ball and implanting our sensors would damage the ball to the point where it may not be playable. We would need precision cuts and be confident before sealing the design without a way to retrieve the pieces if something went wrong. Ultimately, this approach was not chosen because we were afraid of damaging our limited number of IMUs.

5.2 Distance Measurement

Our method of calculating distance went through the most iterations. We played with various ideas like putting a LiDAR emitter into the ball, into the putter, and above the green. The ball was too small to fit a LiDAR sensor, the putter presented issues with the putter not always being where the ball was, and the aerial view proved to be infeasible. For our proposal presentation, we proposed that using a known starting spot, we could use the data from the IMU to map the path of the ball and subsequently calculate the distance. After some research and discussion, we determined that an IMU small enough to fit inside the golf ball will not have the precision nor accuracy to reliably provide us with this data.

5.3 Green

Alongside the distance measurement, our green changed design multiple times. In the beginning, we played to use a circular green much like a practice green found at a golf course. We found it difficult to find a home for the LiDAR sensor and to accurately detect where a ball is with multiple players on the circular green. When we decided, incorrectly, that we could just use the IMU in the ball to do all the distance measurement, we moved toward a circular green that had starting spots in concentric circles at various distances on the green. The starting spots would each have and RFID sensor that would detect the ball at spot X and then using the start distance and balls movement, we could track the end point and thus calculate the distance to the hole. This design was abandoned when the distance tracking with just the IMU was abandoned and we finalized our current design.

5.4 Putter

As mentioned in the distance measurement section, the putter was planned to be fitted with a LiDAR sensor that would measure the distance from the putter to the hole. We decided against this method because when the user is putting, the club will swing back and forth and the exact distance at which the ball is from the hole could vary up to 2 feet depending on the size of the swing. This did not fit our design requirements for distance measurement and resulted in the putter only being fitted with an IMU.

6 SYSTEM IMPLEMENTATION

Our system is composed of 6 subsystems that all interact through various means. (See Fig. 1)

6.1 Green

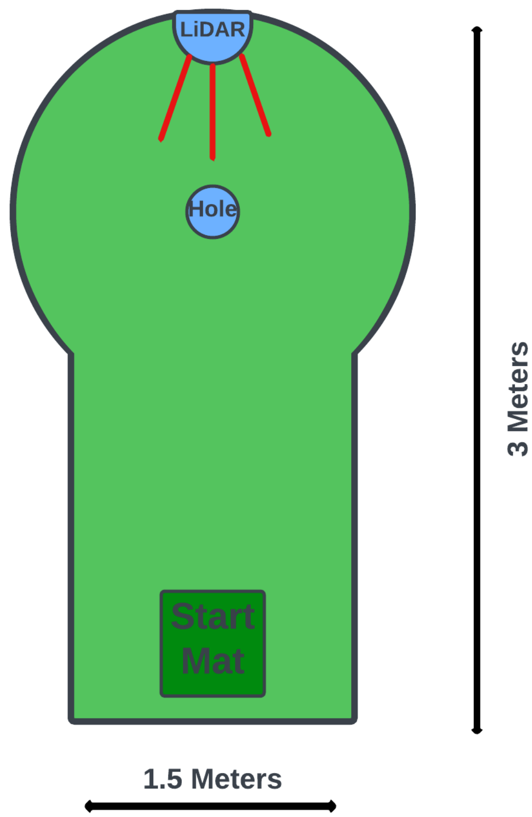


Figure 2: Putting Green Aerial view

Our green will be similar in shape to a standard mini golf hole with a LiDAR sensor placed behind the hole. The green itself will be walled with either wood or bricks not only to contain the balls in the hole but to provide the LiDAR sensors with a ”background” to compare against when trying to detect a ball. The LiDAR sensor will be the primary method to detect the location of the ball and the distance to the hole. This sensor will be connected to a raspberry pi operating as the brains for our sensors through GPIO connections. The start mat (See section Start Mat) will be located at the front of the putting green where the user will be instructed to start. The user will then putt aiming for the hole (See section Hole) placed in the middle of the round section of the green.

6.2 Ball

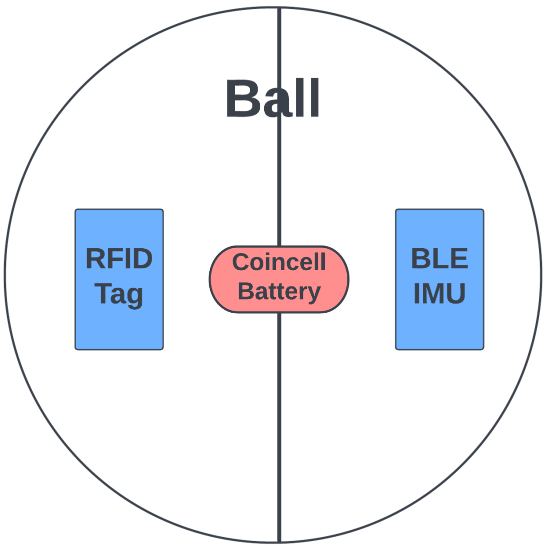


Figure 3: Custom Golf Ball Side View

Our custom golf ball will be similar in size to a normal golf ball (See Section Design Requirements). For communication, we ave identified the SEEED Studio Xiao Microcontroller that comes with an onboard IMU as well as a BLE chip for wireless communication. This microcontroller conveniently uses the Arduino IDE. The chip will allow us to pair the balls with the raspberry pi and receive data about the movement of the ball. The IMU will allow us to detect sudden changes in the ball's movement and match them with movement in the putter (See Section Putter) to detect when the ball is struck. The ball will also have an embedded RFID tag to be scanned by the start mat (See Section Start Mat). This tag will uniquely identify the ball to aid in tracking multiplayer games.

6.3 Putter

The putter will simply be a standard golf putter fitted with the same SEEED studio Xiao microcontroller. This putter will pair with the raspberry pi and send data about the movement of the putter. We will then be able to use this data to match the movement with the movement of a ball (See Section Ball) to detect when a ball is struck by the putter.

6.4 Hole

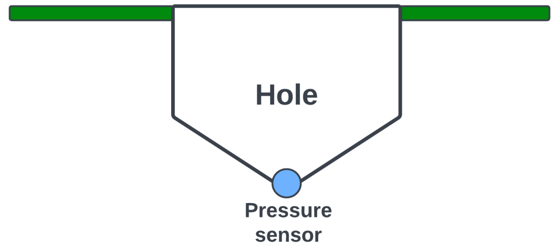


Figure 4: Hole Side View

The hole will be a custom 3D-printed golf hole that matches the diameter of a normal golf hole, 10.8 centimeters. The hole will funnel the ball to the bottom center where a pressure sensor will detect when the ball has entered the hole. This will serve as our method to detect when a putt is made. The pressure sensor will be connected directly through GPIO to the raspberry pi.

6.5 Start Mat

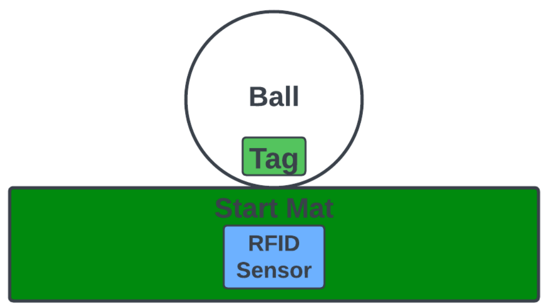


Figure 5: Start Mat Side View

The start mat will be fitted with the RC522 RFID sensor. This will read the RFID tag from the custom golf ball when the user starts. Particularly for multiplayer mode, this will prompt the user to enter their name to assign it to their specific ball. This way we make sure that each ball is struck only when it is that player's turn and keep score for each player. The RFID sensor will be connected via GPIO to the raspberry pi.

6.6 Web App

The Web App, itself, will be hosted on a local computer using a Django Python framework. This data will then be stored using the database system, Postgres. The database system will be integrated with the Django web app framework.

The frontend component will be the user interface. It will be accessible by using a standard HTTP URL. It will be accessible from both a desktop and mobile view. To begin using the web app, the user will specify how many players are playing the current hole. From there, the web app will move to a "player stats" page whereby the web app will begin receiving sensor data thru the backend handlers. The data will be updated and refreshed in real time. including the number of strokes taken, ball position, and spin of the last shot. The updates should be displayed in under 5 seconds. Figure 6 shows our stack diagram below.

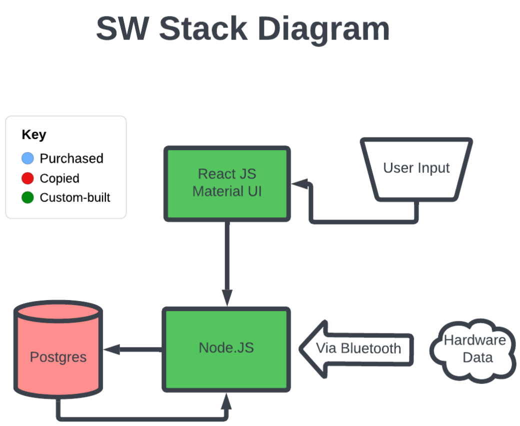


Figure 6: Web App Stack Diagram

The web app consists of two sections: a backend API and a frontend user interface. The backend API will implement five API handlers that fetch various data from a Raspberry Pi:

- Ball IMU data
- Club IMU data
- Lidar Data
- RFID Data
- Pressure Sensor Data

7 TEST & VALIDATION

Each modular component will be tested individually in the following tests.

7.1 Hole Distance Test

The ball will be placed at varying locations on the putting green. It will be put in locations roughly 5 inches apart. The distance from the hole will then be measured directly and compared to the system's estimated distance from the hole. If the estimated distance is within 4 inches of the true distance, the test will be evaluated as successful.

7.2 Club Velocity Test

The orientation and speed of the club swing will be tested individually. First, a golf club grip will be attached to a rotating axis. The club with then be pulled up to a fixed height while attached to the axis and released. In addition, the club will be videotaped using an external camera to get the velocity of the club. Using the video feed, we can time exactly how long it takes for the club to slow down. The velocity can then be calculated accordingly. If the estimated velocity on the IMU is within 0.5 meters per second.

7.3 Club Angle Test

A placemat will be set on the ground with degree lines indicating 5-degree increments. The putter IMU will be calibrated at an arbitrary 0-degree angle. The putter head will then be rotated to match the 5-degree increment lines. The accuracy of the IMU's angle measurements will then be tested against these lines. If the estimated angle is within 3 degrees the test will be evaluated as successful.

7.4 Ball Metrics Test

The custom ball will be rolled down a ramp at different heights to ensure repeatable tests. In addition, the ball will be videotaped using an external camera to get the velocity of the club. Using the video feed, the time the ball rolls can be timed precisely. The velocity of the ball can then be calculated accordingly. If the estimated velocity on the IMU is within 1 meters per second.

7.5 Durability Test

The durability of the ball and the club will be tested. The custom ball will be multiple times around the hole to test that metrics remain accurate using previously described methods. If the ball and club are able to withstand 100 club hits without the system begin compromised or the battery dying, the test will be considered successful.

7.6 Multiplayer Test

To test the multiplayer functionality three balls will be hit by three separate clubs. This test serves as an integration teat for the whole system. a successful test ensures that the metric accuracy persists as in the previous tests.

8 PROJECT MANAGEMENT

8.1 Schedule

Our schedule is fairly strait forward. We purchase all of our parts first, begin work on integration between hardware components and software, then transition to building the webapp, and finally conclude by working on building the green itself. To learn more specifics on our schedule, please see the Gantt chart in Fig. 7 below.

8.2 Team Member Responsibilities

Each team member has a general ECE area of focus that they will be administering for the project. CJ will focus heavily on Hardware component integration, specifically the IMU, the RFID sensors and chips. This includes accuratley reading measurements from the IMU on hit detection, and club angle for specific metrics (See section 2). Seaver's primary focus will be developing and fleshing out the web Application including developing both a front end interface, and a back end database. Erik's primary focus will be on the hardware signal processing, translating each Bluetooth signal into an understandable metric to display on our front end, and to be stored in the database, with the biggest time commitment being the LIDAR signal conversion. Every member also has a secondary focus of building the green, which will need to be elevated to support hardware underneath.

8.3 Bill of Materials and Budget

See Table 1 below for our bill of materials. Our total budget is $600 however we have only used $S196.83 as seen below.

8.4 Risk Mitigation Plans

Our team believes heavily in our design and believe there to be few risks. However we do have a few major risks, which will be managed as follows. Our first risk is that the IMU we have chosen appears to be the only IMU on the market with Bluetooth capabilities, a feature we very much want. However if we cannot manage to integrate this IMU properly that means we will need to change course completely on how to transmit IMU data from within the ball. A backup solution is to purchase an IMU and a Bluetooth transmitter, which together will be able to send data to our workstation. Another risk factor is our Lidar scanner. Lidar scanners are expensive, and the model we are using has been rented out from Carnegie Mellon. If we are not able to properly detect ball locations with this Lidar scanner then we will not be able to use 360 degree Lidar at all due to the high cost of the equipment. Our solution would be to change how we calculate distance, Either via the IMU's internal acceleration and velocity metrics, or from a 1 dimensional range scanner located on the putter's club.

9 RELATED WORK

Our team has found a few similar products in our time researching. One such product is 'Arccos Caddie' by Arccos [1]. Arccos Caddie is able to track putting distance for each shot (as well as track other golf hits throughout an 18 hole game) using a sensor attached to the grip of the club. It detects club velocity and acceleration to determine end ball location. This system is much broader as it covers the entire game of golf completely, and is only able to measure distance, and detect overall trends in your golf game. Best ball provides numerous analytics for a user to enjoy other than hit distance, and is designed only for putting.

10 SUMMARY

Our project sets out to provide the golfer determined to improve their putting with real time feedback and metrics that they can use to improve. With feedback on putting stroke, ball movement, and miss rates from various distances, we hope users of our system can analyze and improve their putting capabilities. Golfers can bring their friends as well and use our system in multiplayer mode allowing them to connect up to three players all receiving feedback and keeping score of the mini game.

Glossary of Acronyms

Include an alphabetized list of acronyms if you have lots of these included in your document. Otherwise define the acronyms inline.

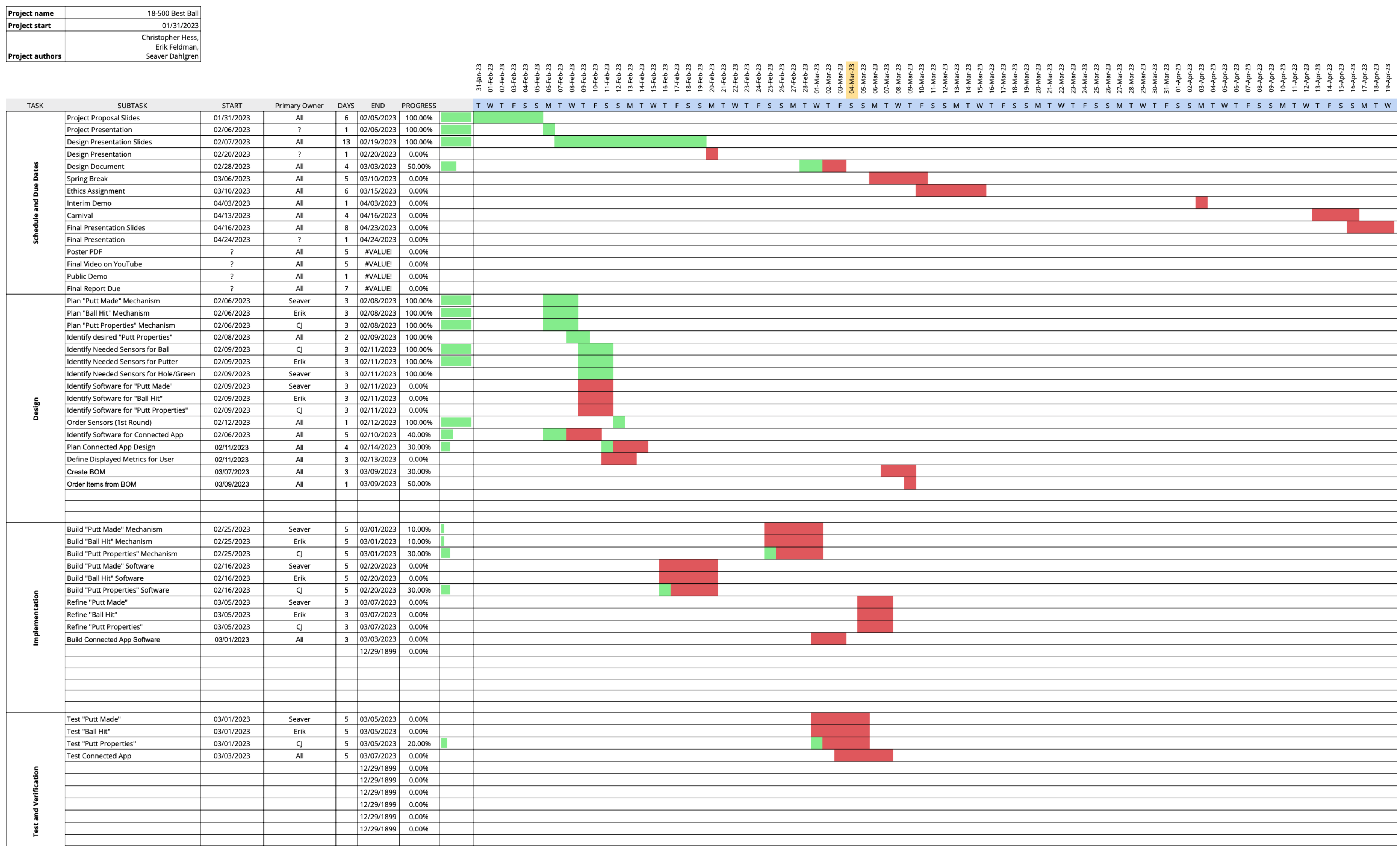
- IMU - Inertial Measurement Unit
- LIDAR (Lidar) - Light Detection and Ranging
- MQTT – Message Queuing Telemetry Transport
- OBD – On-Board Diagnostics
- RPi – Raspberry Pi

References

[1] Arccos Editor. *Arccos Caddie New Feature: Enhanced Putt Tracking.* URL: `https://www.arccosgolf.com/blogs/community/arccos-caddie-new-feature-enhanced-putt-tracking`. (accessed: 03.01.2023).

Table 1: Bill of materials

Description	Model #	Manufacturer	Quantity	Cost @	Total
360 Degree Lidar Sensor	RPLIDAR A1M8	Slamtec	1	$0.00	$0.00
RFID Card Reader	STSx0019	Arduino	2	$4.66	$9.32
RFID Chip	RF-HDT-DVBB-N2	Texas Instruments	4	$2.87	$11.48
IMU with Bluetooth	102010469	Seeed Studio	4	$15.99	$63.96
RFID Flexible sticker chips	F28	FaceGraph	1	$35.00	$35.00
Emerald Green Felt	B001AQEM0M	The Fabric Exchange	1	$26.50	$26.50
Hollow Plastic Golf Ball	B086VX3K65	KOFULL	1	$13.99	$13.99
2 x 4 Lumber (8 feet)	569062	The Home Depot	6	$3.34	$20.04
Pressure Sensors (2 pack)	9SNMYVXW25	Walfront	2	$?8.27	$16.54
					$196.83



TASK	SUBTASK	START	Primary Owner	DAYS	END	PROGRESS
Schedule and Due Dates	Project Proposal Slides	01/31/2023	All	6	02/05/2023	100.00%
	Project Presentation	02/06/2023	?	1	02/06/2023	100.00%
	Design Presentation Slides	02/07/2023	All	13	02/19/2023	100.00%
	Design Presentation	02/20/2023	?	1	02/20/2023	0.00%
	Design Document	02/28/2023	All	4	03/03/2023	50.00%
	Spring Break	03/06/2023	All	5	03/10/2023	0.00%
	Ethics Assignment	03/10/2023	All	6	03/15/2023	0.00%
	Interim Demo	04/03/2023	All	1	04/03/2023	0.00%
	Carnival	04/13/2023	All	4	04/16/2023	0.00%
	Final Presentation Slides	04/16/2023	All	8	04/23/2023	0.00%
	Final Presentation	04/24/2023	?	1	04/24/2023	0.00%
	Poster PDF	?	All	5	#VALUE!	0.00%
	Final Video on YouTube	?	All	5	#VALUE!	0.00%
	Public Demo	?	All	1	#VALUE!	0.00%
	Final Report Due	?	All	7	#VALUE!	0.00%
Design	Plan "Putt Made" Mechanism	02/06/2023	Seaver	3	02/08/2023	100.00%
	Plan "Ball Hit" Mechanism	02/06/2023	Erik	3	02/08/2023	100.00%
	Plan "Putt Properties" Mechanism	02/06/2023	CJ	3	02/08/2023	100.00%
	Identify desired "Putt Properties"	02/08/2023	All	2	02/09/2023	100.00%
	Identify Needed Sensors for Ball	02/09/2023	CJ	3	02/11/2023	100.00%
	Identify Needed Sensors for Putter	02/09/2023	Erik	3	02/11/2023	100.00%
	Identify Needed Sensors for Hole/Green	02/09/2023	Seaver	3	02/11/2023	100.00%
	Identify Software for "Putt Made"	02/09/2023	Seaver	3	02/11/2023	0.00%
	Identify Software for "Ball Hit"	02/09/2023	Erik	3	02/11/2023	0.00%
	Identify Software for "Putt Properties"	02/09/2023	CJ	3	02/11/2023	0.00%
	Order Sensors (1st Round)	02/12/2023	All	1	02/12/2023	100.00%
	Identify Software for Connected App	02/06/2023	All	5	02/10/2023	40.00%
	Plan Connected App Design	02/11/2023	All	4	02/14/2023	30.00%
	Define Displayed Metrics for User	02/11/2023	All	3	02/13/2023	0.00%
	Create BOM	03/07/2023	All	3	03/09/2023	30.00%
	Order Items from BOM	03/09/2023	All	1	03/09/2023	50.00%
Implementation	Build "Putt Made" Mechanism	02/25/2023	Seaver	5	03/01/2023	10.00%
	Build "Ball Hit" Mechanism	02/25/2023	Erik	5	03/01/2023	10.00%
	Build "Putt Properties" Mechanism	02/25/2023	CJ	5	03/01/2023	30.00%
	Build "Putt Made" Software	02/16/2023	Seaver	5	02/20/2023	0.00%
	Build "Ball Hit" Software	02/16/2023	Erik	5	02/20/2023	0.00%
	Build "Putt Properties" Software	02/16/2023	CJ	5	02/20/2023	30.00%
	Refine "Putt Made"	03/05/2023	Seaver	3	03/07/2023	0.00%
	Refine "Ball Hit"	03/05/2023	Erik	3	03/07/2023	0.00%
	Refine "Putt Properties"	03/05/2023	CJ	3	03/07/2023	0.00%
	Build Connected App Software	03/01/2023	All	3	03/03/2023	0.00%
					12/29/1899	0.00%
Test and Verification	Test "Putt Made"	03/01/2023	Seaver	5	03/05/2023	0.00%
	Test "Ball Hit"	03/01/2023	Erik	5	03/05/2023	0.00%
	Test "Putt Properties"	03/01/2023	CJ	5	03/05/2023	20.00%
	Test Connected App	03/03/2023	All	5	03/07/2023	0.00%
					12/29/1899	0.00%
					12/29/1899	0.00%
					12/29/1899	0.00%
					12/29/1899	0.00%
					12/29/1899	0.00%
					12/29/1899	0.00%

Figure 7: Gantt Chart