Sensing and Environment

Motion Sport

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1 Introduction

The **MotionSport** is a mobile application developed as part of the Sensorization and Environment course. This app is designed for a friendly competition among friends through three dynamic games: *kicking*, *punching* and *jumping*. Each game is designed to test and push the limits of participants in fun and engaging ways. Utilizing integrated physical sensors, such as the *accelerometer* and *gyroscope*, **MotionSport** accurately captures and analyzes each motion, providing immediate feedback on performance. This enables a competitive yet enjoyable environment for friends to see who can achieve the best in each challenge.

1.1 Contextualization

In recent years, there has been a growing interest in the integration of technology with physical activities to enhance user engagement and track performance metrics. The **MotionSport** application taps into this trend by combining the excitement of gaming with the physicality of sports. By doing so, it aims to encourage more people to participate in physical activities in a fun and social manner. The application leverages the widespread availability of smartphones and their built-in sensors to make competitive sports accessible to a broader audience, without the need for specialized equipment.

The choice of games — *kicking*, *punching* and *jumping* — was informed by their universal appeal and the ease with which they can be quantified using mobile sensors. These activities do not require extensive training to enjoy and provide a straightforward way for participants to compete with friends. Each game challenges different physical abilities, making the competition diverse and inclusive. The app is designed to be intuitive, allowing users of all ages and skill levels to participate, fostering a sense of community and friendly rivalry among peers.

1.2 Objectives

The primary objective of the **MotionSport** application is to promote physical activity and interaction through gamification. By engaging users in a friendly competition the app aims to make exercise more enjoyable and socially engaging. This not only helps in increasing physical activity among users but also fosters a sense of community and friendly rivalry. Another key objective is to leverage mobile technology to provide immediate feedback on performance, which can motivate users to improve their physical abilities over time.

To achieve these objectives, the app utilizes smartphone sensors to accurately track and analyze each participant's movements. The integration of non-intrusive sensors, *accelerometer* and *gyroscope*, ensures that every action — from the power of a punch to the height of a jump—is recorded with precision. The app processes this data to provide real-time feedback to users, offering insights into their performance and areas for improvement. This immediate feedback loop is crucial for motivating participants to continue engaging with the app and to strive for personal bests in each game.

Moreover, the app is designed with user-friendliness in mind to ensure accessibility for all age groups and skill levels. Clear instructions and an intuitive user interface make it easy for newcomers to start playing without lengthy setups. To further broaden its appeal, the app includes features such as leaderboards, personalized progress tracking, etc. These elements not only enhance the user experience but also encourage ongoing participation and interaction among friends, thereby meeting the app's objectives of increased physical activity and social engagement through technology.

2 State of Art

Before detailing the unique aspects of the **MotionSport** application, it is important to acknowledge several existing applications that also blend physical activity with technology. Apps like **Zwift** [6] and **Strava** [5] are pioneers in integrating digital experiences with physical exertion. **Zwift** has transformed indoor cycling and running by creating virtual environments where users can interact and compete in real-time, while **Strava** utilizes GPS data to track cycling and running activities, offering robust community features and performance analytics.

Another notable application is **Nike Training Club** [4], which provides a wide range of workout routines and training programs, leveraging the smartphone's capabilities to track performance and offer coaching guidance. Similarly, **Fitbit** [2] and other wearable-based apps use accelerometers and gyroscopes to monitor daily activity levels and provide feedback, which encourages users to stay active throughout the day.

These applications demonstrate the effectiveness of using technology to enhance physical activity and user engagement. However, the **MotionSport** app seeks to carve out its own niche by focusing on simple yet competitive physical games that can be played without any special equipment, making it highly accessible. By concentrating on fun, community-driven competition in basic physical activities, **MotionSport** aims to engage users who might feel overwhelmed by more complex fitness programs or isolated by individual tracking apps. This approach hopes to bring a fresh perspective to the integration of technology and physical fitness, emphasizing enjoyment and social interaction.

3 Architecture

MotionSport consists of three key components: **User**, **Smartphone** and **Server**, in this case **Firebase**.

The figure 1 illustrates the system architecture, detailing the applications employed, the storage mechanisms used and the various procedures composing all the project.

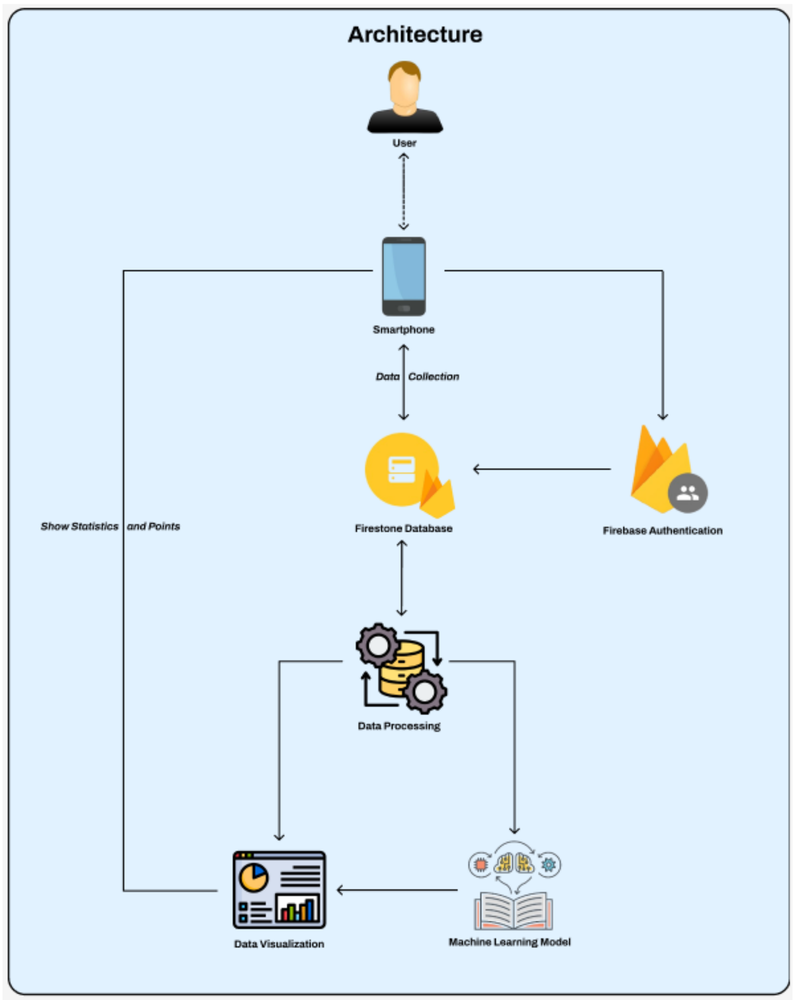


Figure 1: Architecture

As shown in the figure, to use this application, the **User** only needs a **Smartphone**. Once the application is installed, the user needs to register using **Firebase Authentication**. After registration, they can access all available functionalities. Depending on the chosen activity, data from the phone's accelerometer and gyroscope will be collected and stored in the **Firestore Database**. Once this information is saved, a calculation of the user's achieved score is performed, which is also stored in Firestore. Finally, the user can visualize all the processed data, including statistics and performance metrics.

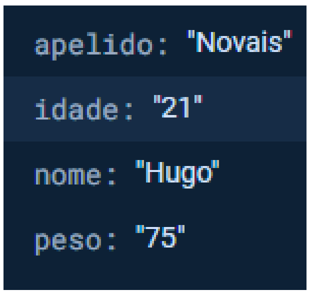
Therefore, it can be stated that the project is structured into two distinct phases:

- **First Phase:** This phase focuses on the design of data collectors, the subsequent collection, and processing of this information.

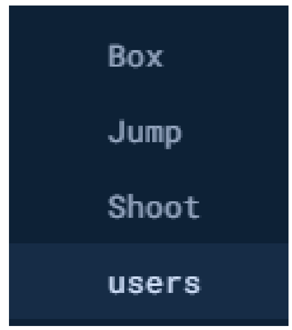
- **Second Phase:** With data collected from different activities, the user can observe various statistics and visualize information about their activities and those of other users. Additionally, the user can see the prediction of the next score in a particular game using the data stored in the first phase with the implementation of a Machine Learning model.

4 Data Collection

Data Collection in the MotionSport app is integral to its functionality. Upon a user's registration, a new document is created within the **users** collection in Firestore. As shown in Figure 2a. This document is named after the user ID assigned by Firebase Authentication and includes fields such as *name*, *surname*, *weight* and *age*, which are gathered during the registration process.



(a) User Document



(b) Collections

Figure 2: User Document & Collection in DataBase

During an activity, data collection is primarily conducted through the app. Each game has its own dedicated collection within the database to store activity logs. When a user initiates a new activity, a new document is added to the corresponding game's collection. This document includes the *user's ID* and the *timestamp* of the activity. Attached to this document are two sub-collections: **AccelerometerData** and **GyroscopeData**. AccelerometerData contains documents with fields for *accelerometerX*, *accelerometerY*, *accelerometerZ* and their respective *timestamps*, recording the data captured by the accelerometer. Similarly, *GyroscopeData* mirrors this setup but for the gyroscope sensor, capturing orientation and angular velocity data.

Upon the completion of a game, the data are processed and scores, along with the force exerted or the height achieved depending on the game mode, are recorded for that activity. All of these aspects are depicted in the Figure 5.

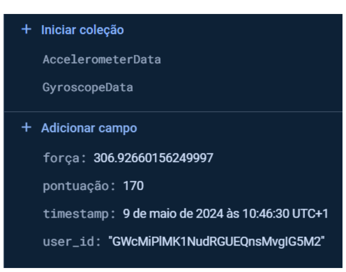


Figure 3: Box Document

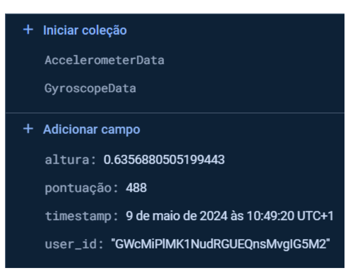


Figure 4: Jump Document

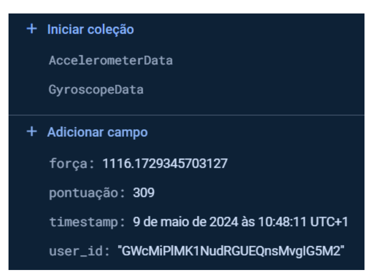


Figure 5: Shoot Document

In the data collection process, two physical sensors are utilized:

- **Accelerometer**: Measures the acceleration forces caused by movement or gravity, aiding in the detection of changes in speed and orientation.

- **Gyroscope**: Measures or maintains orientation and angular velocity, typically used to stabilize or track movement.

Furthermore, similar to practices in our courses, we employ the **SensorManager** class to access sensor data and the **SensorEventListener** to continuously collect data.

The final step in activity - related data collection involved setting up a data collector. The team opted to use Firebase's Cloud Firestore due to its flexibility and lack of monetary costs. To ensure privacy and individual data segregation, a separate Firebase project account was created for each user, where their data are stored individually.

Continual data collection is managed by the MotionSport app, which consistently stores relevant information in the database when an activity start.

This system allows the application to be used in any **environment** as long as the user has sufficient space to perform the activities, thereby facilitating an incentive for physical activity.

5 Exploration and Processing of Data

The exploration and processing of data were tailored to each game within the application. Each game presented unique challenges and required specific analytical approaches to effectively measure and enhance participant performance. In the following section, we will detail how data were individually processed and analyzed for each *kicking*, *punching* and *jumping* to ensure accurate performance tracking and meaningful feedback for participants.

5.1 Jump

The score assigned to the jump comes from the maximum height reached during it. To calculate the maximum height, we start from the **Principle of Conservation of Energy**.

Kinetic Energy can be expressed as:

$$\mathrm{EC} = \frac{1}{2}mv^2 \tag{1}$$

Potential Energy is given by:

$$\mathrm{EP} = mgh \tag{2}$$

The equation relating **Kinetic Energy** and gravitational **Potential Energy** is:

$$\frac{1}{2}mv^2 = mgh \tag{3}$$

Cancelling the mass m, we obtain:

$$\frac{1}{2}v^2 = gh \tag{4}$$

Reorganizing to obtain the height h in terms of velocity v and acceleration due to gravity g, and substituting $v = gt$, we obtain the height h in terms of time t and acceleration due to gravity g:

$$h = \frac{(gt)^2}{2g} \tag{5}$$

Simplifying, we arrive at the final equation:

$$h = \frac{t^2 g}{2} \tag{6}$$

Considering gravity as 9.81 m/s^2, our primary focus is on determining the duration of the jump. To achieve this, we utilize the data obtained from the accelerometer.

The jump duration is computed by measuring the time gap between the initial recording and the moment when the individual reaches their maximum height. To identify this specific moment, we locate the first occurrence of a negative peak in accelerations along the Z-axis. This choice is informed by the fact that during the ascending phase of the jump, vertical acceleration tends to be negative, reflecting deceleration. Hence, the initial negative peak marks the instance of maximum vertical deceleration, indicating the point of reaching the peak height.

Following the calculation of height, we apply a multiplicative factor to obtain a score between 0 and 999,for punches, this factor is **769**.This information is stored in the database.

5.1.1 Jump Failed Attempt

In a first attempt, we try to calculate the height through the speed and the jump time using the following formulas:

1. Integration of acceleration to obtain velocity:

$$v(t) = v_0 + \int_{t_0}^{t} a(\tau)d\tau$$

where:

- $v(t)$ it's velocity as a function of time.
- v_0 it's the initial velocity.
- t_0 It's the initial time.
- τ it's the integration variable.

2. Integration of velocity to obtain height:

$$h(t) = h_0 + \int_{t_0}^{t} v(\tau)d\tau$$

where:

- $h(t)$ it's the height as a function of time.
- h_0 it's the initial height.
- t_0 it's the initial time.
- τ it's the integration variable.

However, since gravity affects the values of acceleration, we had difficulties in ignoring its influence for jump calculation. Using this formula, the heights obtained were exaggerated.

5.2 Box

The score attributed to the punch corresponds to the force it generates. This force is determined by identifying the maximum absolute value of the instantaneous acceleration recorded throughout the motion.

The force can be calculated using the following formula:

$$F = m * a \tag{7}$$

where m represents the body mass and a the acceleration.

To calculate the punch force, we multiply the mass by 0.06 [1], as an arm typically represents about 6% of the mass of the human body. This yields the following formula:

$$F = m * a * 0.06 \tag{8}$$

From this formula and considering the principles of unit conversion for rotation, we conclude that we should take into account the rotation of the movement, thus adding the angular velocity *alpha* to the formula for calculating the movement:

$$F = m * a * 0.06 * \alpha \tag{9}$$

The acceleration is obtained using the following formula, with the values collected from the accelerometer of the mobile device. The instant from which we retrieve the values of the three accelerometer components is the instant when it has the highest absolute value.

$$a = \sqrt{(accelerometerX)^2 * (accelerometerY)^2 * (accelerometerZ)^2} \tag{10}$$

Angular velocity is obtained using the following formula, with the values collected from the gyroscope of the mobile device. The instant from which we retrieve the values of the three gyroscope components is the instant when it has the highest absolute value.

$$\alpha = \sqrt{(valueX)^2 * (valueY)^2 * (valueZ)^2} \tag{11}$$

Finally, we apply a multiplicative factor to obtain a score between 0 and 999. For punches, this factor is **0.555**. It is crucial to note that this factor was not arbitrarily chosen. Extensive research was conducted on the average force that a punch can generate, encompassing normal individuals, boxers and even MMA fighters [3]. Following this research and group tests, it was determined that a punch surpassing 1800 Newtons achieves the maximum score. Anything below this threshold is multiplied by the factor to yield a value between 0 and 999. Thus, by dividing 999 by 1800, we arrive at the multiplicative factor used.

Once the force and score are calculated, this data is also stored in the database.

5.3 Shoot

Similar to the punch, the score assigned to the kick is based on the force it generates. The formula used to calculate this force in Newtons resembles the one used for calculating punch force. The only difference is the multiplier, which changes from 0.06 to 0.17 , reflecting the fact that a leg constitutes approximately 17% of the mass of the human body [1]. Thus, the formula becomes:

$$F = m * a * 0.17 * \alpha \tag{12}$$

The acceleration and angular velocity are obtained in the same way as they are for the punch formula.

Finally, we apply a multiplicative factor to obtain a score between 0 and 999. For kicks, this factor is **0.2775**. It's essential to note that this multiplicative factor wasn't chosen arbitrarily. Research was conducted on the average force that a kick can generate, encompassing both normal individuals and professional football players [7]. After this research and group tests, it was determined that a kick surpassing 3600 Newtons achieves the maximum score. Those below this threshold are multiplied by the factor to yield a value between 0 and 999. Thus, by dividing 999 by 3600, we arrive at the multiplicative factor used.

Once the force and score are calculated, this data is also stored in the database.

6 Data Visualization

In this phase, the manner in which data are presented plays a crucial role in achieving our goal of encouraging people to maintain their physical activity. Effective data visualization is not only about displaying data but also about making it accessible and engaging for users. By employing various types of graphical representations, we can illustrate progress, highlight achievements, and reveal patterns that may not be immediately apparent through raw data alone.

Interactive charts and real-time feedback graphs are particularly powerful in motivating users by allowing them to see the immediate impacts of their activities. For example, line graphs can show progress over time, bar charts can compare performance between sessions, etc. Each graphical type is chosen based on its ability to communicate specific aspects of the data clearly and effectively.

Ultimately, our approach to data visualization aims to inspire continuous engagement with the **MotionSport** app, helping users to visually track their fitness journey.

6.1 Main Menu

As shown in the Figure 6, the main menu of the application is intuitively designed to immediately engage users with key features. Prominently displayed at the center is the **Daily Goal**, which tracks the user's progress towards completing ten activities each day. This goal is visually represented by a pie graph, offering a quick and effective overview of how many activities have been completed and how many are still pending.Adjacent to the daily goal, the **Check Activities** allows users to delve deeper into their performance metrics. This section utilizes a combination of pie charts and radar charts to provide a detailed analysis of activity types and performance metrics across different games. Such detailed visualizations help users understand their strengths and areas for improvement, enhancing the interactive experience of tracking fitness progress.

Additionally, the **Total Activities** counter is displayed on the main menu, providing a quick summary of all the games completed by the user to date. This feature serves as a continuous motivator, encouraging users to increase their activity count and set new personal records.

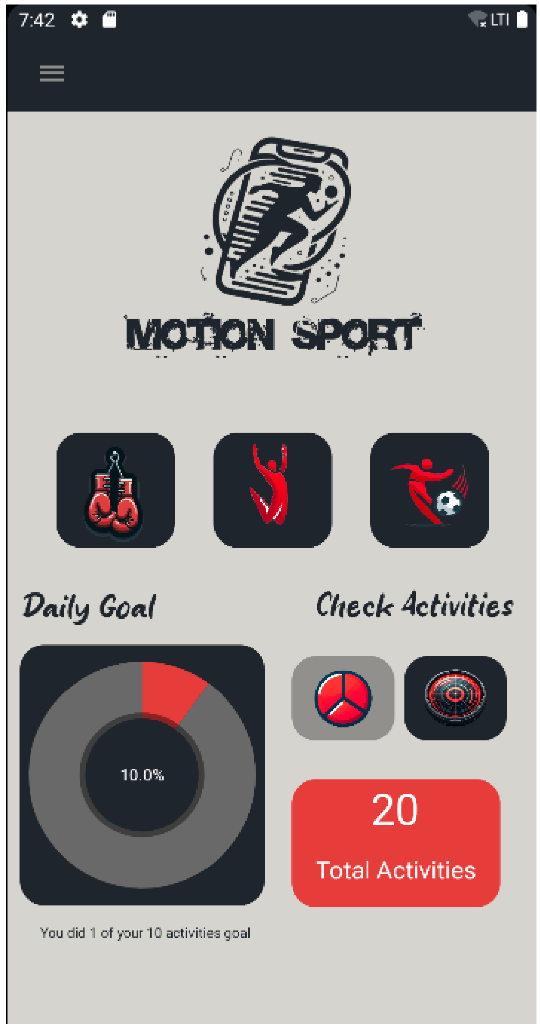


Figure 6: Main Menu

In addition to the information previously mentioned, it is possible to view four distinct types of data.

6.2 Games Played

One such type, **Games Played**, is displayed using a **Pie Chart**. This allows users to see their activity percentage in each of the available games. Consequently, users can gauge which game they have played the most, potentially encouraging them to diversify their activities to keep the chart balanced. Furthermore, by clicking on any segment of the pie chart, users can view the actual count of activities, such as the number of jumps performed, if they wish to know specific details.

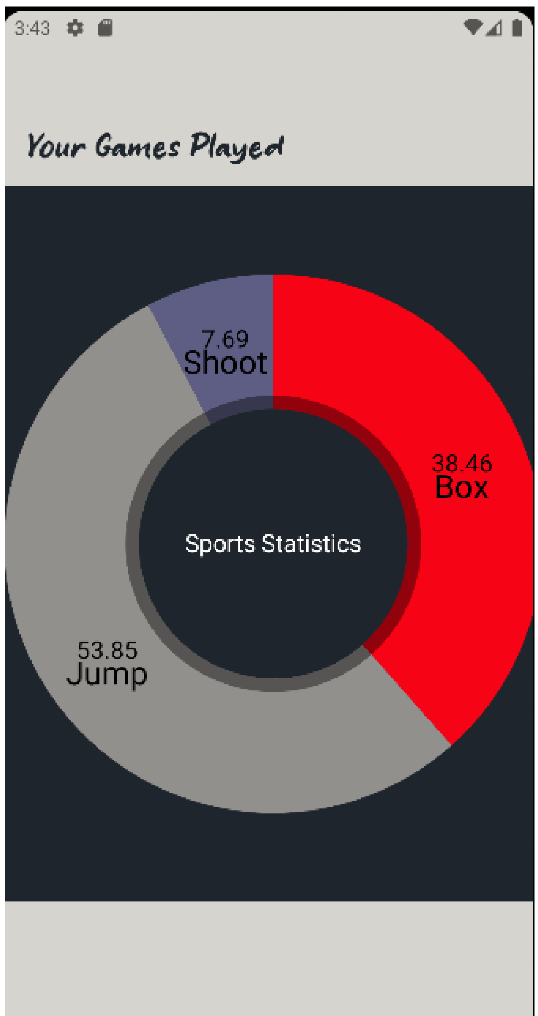


Figure 7: Pie Chart

6.3 Player Skills

Player Skills are displayed using a **Radar Chart**, a graphical tool commonly used in various types of games, thus making the user experience more familiar. This visualization allows users to see their best scores in each of the games. Moreover, to further motivate users to continue their physical activities, it is possible to compare one's scores with those of other users. This feature encourages competitiveness and engagement among participants by showing how they measure up in different skill areas.

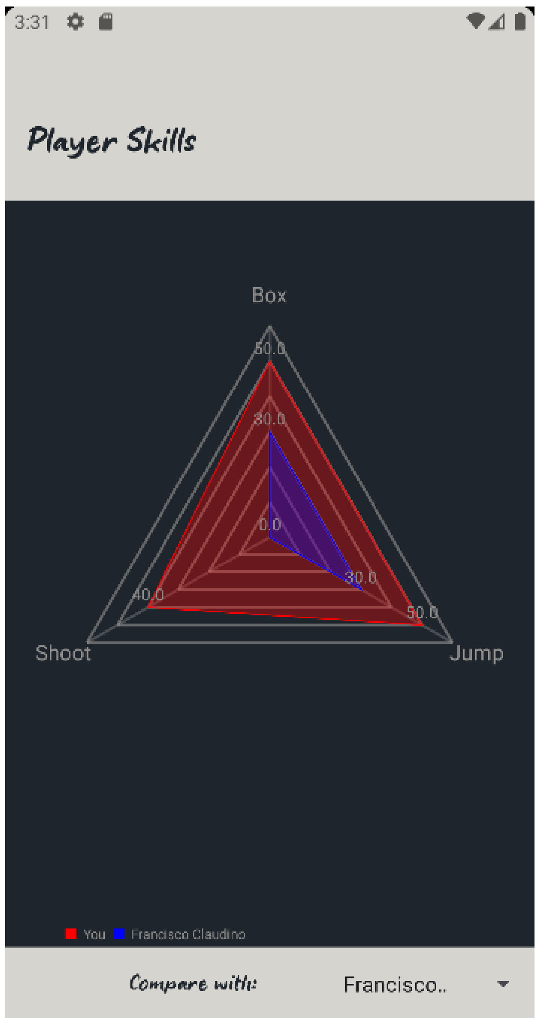


Figure 8: Radar Chart

6.4 Player Evolution

Player progression is depicted through a **Line Graph**, which illustrates the evolution of a player's scores over their last several attempts. By default, the graph displays the last five scores, but users have the option to adjust this number to view more or fewer data points. Additionally, as shown in the graph, there is a predictive element; the application uses a Machine Learning model to forecast the player's score for the next activity. This predictive feature not only adds an innovative aspect to the user experience but also aids in setting goals and expectations for future performance.

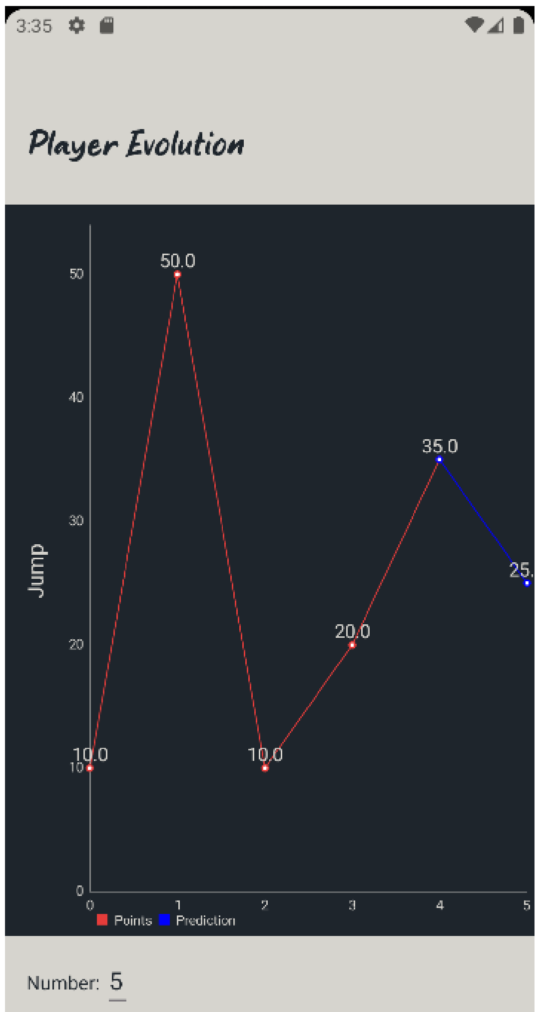


Figure 9: Line Chart

6.5 Leaderboard

As with any competitive game, with the ongoing goal of encouraging people to engage more frequently in activities and continuously improve their results, we present a leaderboard for each game. This leaderboard is visualized using a **Bar Chart** that displays the top five scores achieved in the game along with the users who attained these scores. By showcasing these rankings, we aim to motivate users to strive for the highest possible scores, which we anticipate will lead to an increase in their overall activity level.

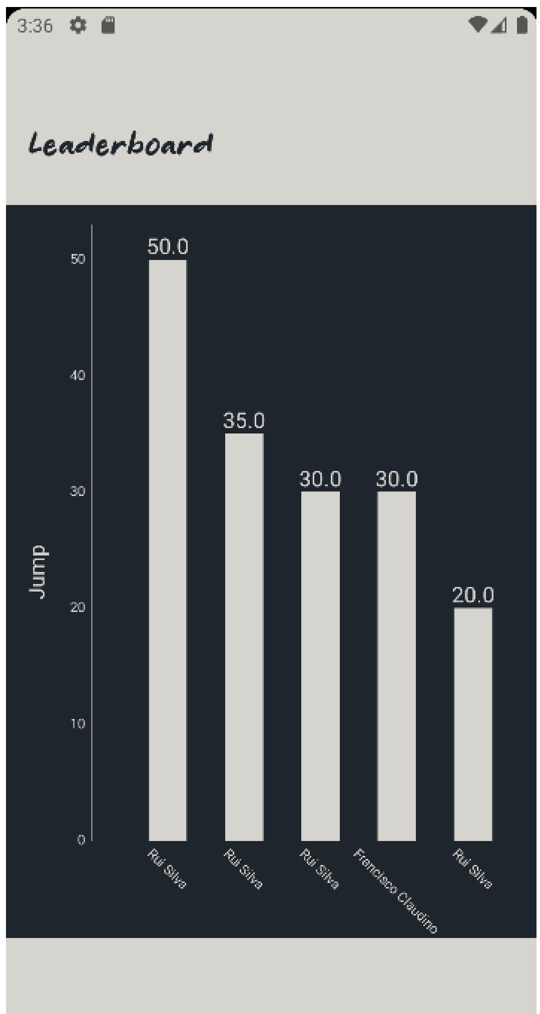


Figure 10: Bar Chart

7 Video Demo

In order to demonstrate all the previously discussed capabilities, the following demo video showcases the real-time results and navigates through the application. The video can be viewed at: `https://youtu.be/yJSFMmUGv38`

8 Predictive Function

To predict the next score, we collect all the previous scores of the player and use the function `estimativaProximaPontuacao()` to make the prediction. The calculations performed within this function are:

- **Calculation of Mean and Standard Deviation:**

  First, we calculate the mean of the scores, which represents the typical value of a data set. Then, we calculate the standard deviation, a measure of dispersion that indicates how far the values in the set deviate from the mean. This provides an idea of how spread out the values are.

- **Correlation Coefficient:**

  The correlation coefficient is a statistical measure that describes the strength and direction of a linear relationship between two variables. In this case, we calculate the correlation between the scores and their positions in the list. If the standard deviation is zero, the correlation coefficient will also be zero, indicating no variability in the scores.

- **Slope and Intercept of the Regression Line:**

  To find the equation of the line $y = mx + b$, we calculate the slope of the regression line. This is done by multiplying the correlation coefficient by the standard deviation and dividing by the size of the score list. This gives us m, the slope of the line that best fits the data. The intercept of the regression line is calculated as the mean minus the product of the slope and half the size of the list. This gives us b, the point where the line intercepts the y-axis.

- **Estimated Next Score:**

  Finally, we estimate the next score using the previously described line equation, substituting x with the next number in the sequence of score positions.

9 Business Model Development

As part of the **MotionSport** app project, it is imperative to develop a robust business model that demonstrates the practical viability of the conceived solution in real-world contexts. This section outlines our strategic approach to studying and defining a sustainable business model for the application.

9.1 Customer Identification and Characterization:

The potential customer base for **MotionSport** primarily includes casual exercisers and fitness enthusiasts who enjoy social interaction through sports but may lack the motivation or means to engage in traditional sporting environments. These users are likely to be tech-savvy individuals who appreciate the integration of technology with physical activity. Additionally, the app targets younger demographics, such as students and young professionals, who are often engaged with mobile technology and social media.

9.2 Partnerships:

Forging strategic partnerships will be crucial to the success of **MotionSport**. Potential partners include fitness equipment manufacturers, sportswear brands and health and wellness organizations. By collaborating with these entities, **MotionSport** can enhance its product offering — such as through co-branded challenges or integrated gear — and expand its market reach. Another avenue for partnerships could involve local sports clubs and wellness centers, where the app could be used to organize local competitions and community events.

9.3 Monetization Strategy:

The monetization strategy for **MotionSport** involves multiple revenue streams:

1. **Freemium Model:** The app will be free to download with basic features accessible at no cost. This free version will be supported by advertisements, primarily from fitness-related businesses and wellness brands. The ads will be strategically placed to maintain user engagement without disrupting the gameplay experience.
2. **Premium Subscription:** For users who prefer an ad-free experience, **MotionSport** will offer a premium subscription. This subscription will not only remove ads but also unlock additional features, such as advanced performance analytics and exclusive access to special competitions and challenges. This dual approach allows users to choose the version that best fits their needs and preferences, while also providing a clear upgrade path for enhanced features and benefits.
3. **Sponsorships and Events:** The app could host sponsored events or challenges, where brands can sponsor competitions or specific challenges within the app.
4. **Merchandising:** Sale of branded merchandise or partnerships with sportswear brands to offer products through the app.

By addressing these key areas, the business model for **MotionSport** aims to not only be sustainable but also scalable, adapting to new trends and user needs as the fitness technology market evolves.

10 Critical Analysis and Future Work

After the development of this project, various ideas for improvements surfaced, diverging from the initial concepts. Initially, following feedback from participants during a testing phase, it became evident that the interface could be enhanced. Additionally, upon thorough self-assessment of the project, it became apparent that the equations used for predicting force and height might benefit from refinement. Seeking consultation from physics experts to optimize these equations and explore the integration of additional sensors if necessary could significantly improve the accuracy of user scores, ensuring a more reliable experience.

Looking forward, the group envisions transforming the application into a social network where users can forge friendships with other players. Implementing a notification system to alert users whenever their scores are surpassed would further enhance the competitive and social aspects of the app. By fostering a sense of community and friendly rivalry, these planned enhancements align with the app's overarching objectives of increasing physical activity and social engagement through technology.

11 Conclusion

The completion of this project has significantly deepened our understanding of the design and implementation of environmental sensor systems. Additionally, it has facilitated the development of skills related to data processing and the various methods of data presentation.

Concerning the primary goal of the project, which is to encourage physical activity and friendly competition, our findings during the application testing phase were quite positive. Users enjoyed interacting with the app, and the competitive elements implemented led to an increased number of activities being performed. This indicates that gamification can effectively motivate users to be more physically active.

The team believes that the objectives set out for the development were successfully achieved. A highlight of the project was the creation of the Android application, a task that was a first for every member of the group. This achievement not only represents a significant technical accomplishment but also a valuable learning experience in mobile app development.

In conclusion, having addressed these details, we are eager to publish our application on a platform like the Google Play Store. This will make it accessible to a broader audience, helping more people to stay active. By moving into a public domain, we aim to gather more user feedback, which will be invaluable for further improvements and enhancements to the app. This step will also allow us to measure the real-world impact of our application on encouraging physical activity and friendly rivalry among users.

References

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[2] Fitbit Official Site for Activity Trackers & More — fitbit.com. https://www.fitbit.com, fitbit is a company known for its products that track daily activity, exercise, sleep, and weight. Their devices utilize sensors like accelerometers and gyroscopes to monitor and motivate user activity levels.

[3] Impacto do soco e do chute dos esportes de combate: uma revis&xE3;o sistem&xE1;tica — Pensar en Movimiento: Revista de Ciencias del Ejercicio y la Salud — revistas.ucr.ac.cr Analysis of the force generated by the movement of a punch in boxers and MMA fighters. Analysis of the force generated by the movement of a shot in professional soccer players.

[4] Nike training club. https://www.nike.com/ntc-app, nike Training Club offers a variety of workouts ranging from bodyweight-only to full equipment workouts, designed for different fitness levels and goals. The app also provides guidance and motivation from Nike's coaches.

[5] Strava — Running, Cycling & Hiking App - Train, Track & Share — strava.com. https://www.strava.com, strava is an app primarily used for tracking cycling and running using GPS data. It offers extensive social features, allowing users to connect with other athletes, join challenges, and share their workouts and routes.

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