Court Vision: An application to measure the performance of Wheelchair Basketball players

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1. Abstract
Over the last few years, sports analytics has become an increasing area of research and development. It is a collection of relevant data which when presented properly can provide a competitive advantage to a team or individual [71]. Sports analytics was brought to the public eye by the movie Moneyball [72] which was an adaptation of a book by Michael Lewis by the same name. Nowadays, teams from all sports are spending huge amount of money to gather relevant data which can be later analyzed for performance improvement. This has led to increasing number of companies building software and providing services for this purpose. These software are often expensive and require high computational power which makes them impractical to small teams and clubs.

In this project, I explored the possibility to creating a system for measuring the performance in wheelchair court sports. Wheelchair basketball, being one of the most common wheelchair court sports, was chosen for this purpose. Outcome of the project is “Court Vision”, a low-cost prototype for tracking players and presenting the captured data in an efficient manner to coaches and players. Court Vision is created with the aim to help the teams in improving their performance. An iterative design process was used for developing the system and various computer vision techniques and sensors were explored for tracking of players and the ball.

Author Keywords
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ACM Classification Keywords
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Design / Artefact

2. Introduction
Wheelchair sporting events were first introduced as part of rehabilitation program for individuals following spinal cord injury in Second World War era [27]. Since then, the popularity of wheelchair sporting events has increased with many competitive events worldwide. Wheelchair basketball is one of the most popular wheelchair sporting events. It is both a mainstream game in which wheelchair users and non-wheelchair users can participate in a team and is also played part of Paralympics Games as well, where teams are entirely composed of disabled people.

Quality of life (QOL) in people with physical disabilities has been widely studied across various fields of social, medical and behavioral sciences [49, 50]. The aim of these efforts is to understand and improve the Quality of Life for disabled individuals. Studies have also shown that individuals with spinal cord injury who participated in sporting events had a better satisfaction in life [30, 31]. Increased physical activities can also help in reducing the risk of cardiovascular diseases with spinal cord injury [29]. [48] suggests this is not just limited to spinal cord injury individuals but is applicable to all wheelchair users in general. Various forms of physical activity have been shown to result in substantial gains in strength and overall functioning of individuals with physical activities [48]. The same study also suggested that the wheelchair basketball players become more confident about their capabilities of performing general mobility tasks. Wheelchair basketball, like other sports can improve health and wellbeing outcomes, including mental health; with a definite relationship being found between playing competitive wheelchair basketball and improved mental health [47].

Technology advancements and increased opportunities have also resulted in increased participation of people with disabilities in
various sports [28]. As of 2006 there were around 100,000 people who played wheelchair basketball worldwide [1]. These included recreational players to elite national team members. At the time of writing, the International Wheelchair Basketball Federation (IWBF) had 105 National Organizations for Wheelchair Basketball (NOWB) worldwide with its number increasing every year [2]. Even with these increasing numbers, there isn’t much support available to measure the performance of players, especially during their practice at a local level. There are various tools in the market for measuring performance of players [40, 41, 42] which are used at professional levels and at events such as the Paralympics, but they are very expensive for a local club or team. Because of the lack of tools, coaches are often not able to quantify various performance metrics. In a study carried out last year [61], researchers, while looking for future potential of fitness technologies for stamina and fatigue management in wheelchair basketball, found that the key metrics requested by the coaches for measuring the performance of players were top speed, average speed in a game, total distance travelled and position of players at different times.

This project is a logical extension of an undergraduate project done earlier this year [85]. User requirements found during research in [85] are similar to the ones mentioned in [61]. The purpose of this project is to equip coaches with a tool which is low cost and can provide much needed quantifiable data. The primary objectives of this project are to build on previous work, which explored the requirements of a system to help coaches and to contribute “Court Vision”. Court Vision tracks the location of players and the basketball during a training session or game. It can calculate a wide range of matrices such as total distance travelled by a player in a game, total number of baskets scored, and number of passes made during the game.

Various techniques in computer vision and sensors were explored to capture these details, and the resulting methods are described alongside the visualizations used to present the data back to coaches in an easy to understand way. It can help the coaches to analyze the performance of individual players. Players can also log in to the system to view their performance. So, it can be used as a performance review system as well.

3. Background

3.1 Performance Analysis

Measuring performance of players is an important aspect of any sport. It is a specialized discipline involving systematic analysis to enhance performance and improve decision making [38]. Performance analysis in sports is defined as the analysis of data or information to help in the acceleration of athlete performance [39]. It provides the athletes and coaches with objective information which is then used to optimize team and player performance. Performance analysis can be useful in many ways because, it provides information about the performance of a team or player in any game or season. It also provides an overview of team’s skills including its strength and weaknesses. And finally, it quantifies a player’s or team’s performance. Because of these reasons, performance analysis in sports has gained a lot of attention in the past few years. Various systems and prototypes have been created for this purpose. Performance measuring systems can be broadly divided into 2 types:

3.1.1. Body worn devices

Wearable fitness devices, like Fitbit are being increasingly used by people to monitor their physical activity. These devices can track information like step count, calories burnt and heart rate among other things. Although fitness wearables revenue is expected to be $26.48 billion in 2018 [77], these devices are not widely
adopted by wheelchair users [78]. Authors in [78] have argued that one of the major reasons for the low adaptation is that most of the fitness devices measure physical activities as “steps”. This leads to the misperception that the technology is not capable of measuring the movements of wheelchair users. Wheelchair based tracking systems have been explored by researchers although this work is only in its infancy. [79] introduces a concept of Chairable Computing, which among other things, explores various ways in which fitness tracking can be accomplished for wheelchair users. It also focuses on fitness tracking for wheelchair basketball players. One of the implementations of Chairable for performance measurement of wheelchair basketball players is presented in [86], where the authors have created prototype consisting of various sensors like Wi-Fi-enabled microcontroller and 9-axis IMU which measures various tracked metrics including average speed, acceleration, distance travelled and top speed. Another example is SpokeSense [76]. SpokeSense is a fitness tracker for wheelchair athletes. It consists of a variety of sensors which fit into a small, laser-cut case which is then attached to the wheelchair. These sensors measure various core metrics including speed, distance, intensity zones, acceleration and braking of wheelchair. However, both these systems are unable to locate the players at any instant which is an important requirement for game analysis.

3.1.2 Vision based/external systems

Camera based systems are currently widely used for tracking players in sports. Almost all the professional sports use vision-based tracking systems for measuring the performance of players. Although, now allowed, GPS based wearables were not allowed in competitive sports till recently, like in soccer [80]. A major limitation of GPS technology is its reliance on satellite signals restricting its use to outdoor environments only. As a result, indoor sports like wheelchair basketball and wheelchair rugby cannot utilize GPS.

Given the limitation with the GPS based tracking solutions in indoor sports, the most reliable solutions available for tracking position of players are vision-based tracking systems and sensor-based tracking systems, which are analyzed further below.

Another important aspect of performance analysis is data sharing. Data from various metrics is captured and shared with other people (coach, other players and viewers). Although, [86] found that wheelchair basketball community, in general is less concerned about the privacy of their data and athletes are motivated by competition and work done in [87] also suggest that sharing data with peers is an engaging experience, care should be taken to minimize any privacy issues. During the interviews done in [86], some of the players raised these concerns and mentioned that some control over data should belong to them and that not everyone should be allowed to view their data. During my interviews as well, the coaches mentioned that only coaches should be able to view all players’ data and it should not be visible to other players.

3.2 Vision-based tracking

Tracking of moving objects has been an area of active research in computer science, especially computer vision. It becomes particularly difficult when the sport has multiple players or fast-moving objects [36]. Basketball is one such game with 10 players at any point of time and a relatively fast-moving ball. Player tracking is an important aspect of performance analysis as well. A lot of information can be extracted by tracking a player in a field or court. In recent years, a significant amount of work has been done to analyze the players abilities and performance across a variety of sports, examples include, techniques which track players and
allow for their positions and movements to be analyzed [33, 34]. Various professional systems and prototypes have been created for different sports to analyze the performance of players [40, 41, 42]. Interplay sports [41] is one of the early professional systems created for this purpose. In this system, the analysis is done manually where all the video streams are manually annotated and then analyzed. On the other hand, SportsVU [42] uses cameras installed in a basketball court to track real-time position of the players and the ball. This tracking data is then utilized to create various metrics. Bagadus [40] is another prototype created by combining different methodologies. It uses both camera and sensors to gather data during a match and then the analytics system is used to generate meaningful information from gathered data.

Various methods have been employed for the analysis of basketball games. Primary methods include processing of Basketball match videos using computer vision techniques [9, 35]. Over the past few years, particle filters also have proved to be a powerful tool for tracking players in a game [3, 4, 5]. This is a hypothesis tracker which approximates the position of a moving object based on a set of weights. The Kalman Filter [32] is one such filter which has been used extensively for this purpose [6, 7]. Kalman Filter is used to estimate the trajectory of moving objects (players and the ball) based on previous positions. Graph techniques have also been used for tracking multiple players in [8, 9]. In the graph techniques, detections from each frame are combined to estimate the most likely trajectories of objects. This process could become complicated. Both these methods also pose other problems like camera calibration, object occlusion and synchronization issues.

With the advancements in Deep Learning (DL) especially in Convolutional Neural Networks (CNN) in recent years, a lot of research on object tracking has begun to focus on using CNN. In [45], authors proposed a model which learns to detect events in a video. These events could be a player attempting a shoot or a block by another player. Similarly, in [46] authors have proposed a method to predict the likelihood of a player making a shot. CNNs became an area of active research after the creation of AlexNet [37] which won the ImageNet competition in 2012. Both Kalman Filter and Convolutional Neural Network are used to estimate parameters from a stream of data (in this case, player and ball positions). While in Kalman Filter, the model is explicitly written in form of equations, in a CNN, no explicit model is defined initially. It is learned by looking at many examples and by using various optimization schemes to understand the best set of transformations. Because a CNN learns by looking at examples, the training requires huge amount of data. Although, Kalman Filter is easy to implement and often gives reasonably good results, it does not give satisfactory results in case of sudden movements like when a player stops a ball in flight. CNNs does not have this issue and can easily detect such changes. Although CNNs are very powerful, they are difficult to build and often require a lot of time and computational power for the model to train. Because of time constraints, the premise of CNN was not further explored in this project.

3.3 Sensor based tracking systems

Because of the constraints of GPS systems, radio frequency-based sensors are mostly used for tracking players in indoor sports. [10] introduces a new system called Wireless Ad-hoc System for Positioning (WSAP) developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) for tracking in indoor environments. Similarly, in [11] authors have used radio waves to track players in indoor basketball. But the results were found to be unsatisfactory in that the system cannot be used for real-time tracking of players. [81] investigates the validity and reliability of a radio frequency-based system for accurately tracking athlete
movement within wheelchair court sports. It uses an Indoor Tracking System (ITS) which is a wired radio frequency-based real-time location system developed by Ubisense, UK. The results suggest that the ITS is a suitable system for quantifying both static and dynamic measurements specific to wheelchair court sports. Another radio-signal-based solution called Local Position Measurement (LPM) was introduced in [83]. It relies on the distance measurements between fixed base stations and mobile tags based on the frequency modulated continuous wave principle. Comparisons between LPM and ITS was done in [84] and it was found that LPM outperforms ITS by approximately a factor of 2 in terms of accuracy and approximately by a factor of 7 in terms of sampling rate.

Recently researchers have also explored the possibility using RFID sensors for tracking players in a court game. [82] uses several radio receivers placed around the court in such a way that the entire playing area is within radio reception range of at least three receivers. The players should wear RFID tags which transmit signals. Signal triangulation is then used to determine the exact location of the players.

Bluetooth sensors can also be used for tracking purposes. With the introduction of Bluetooth Low Energy (BLE) beacons like Apple’s iBeacon [12] and Google’s Eddystone [13], objects can be tracked by creating a mesh of sensors and calculating the RSSI value of received signal and doing triangulation to get the exact location. Court Vision uses a similar Bluetooth sensor called Estimote [62] Ultra-Wide Band (UWB) Bluetooth beacons for tracking the players.

Because Court Vision is designed in a way that the player tracking is independent of the visualization and user interface, any of the above-mentioned techniques can be used for tracking the players. Once the data is available in the database, the Court Vision system is capable to calculate all the metrics and present it to the user.

3.4 Visualization
Visualization relates to different meanings within different contexts [14]. For example, there are scientific visualizations where the use of visual images aids the understanding of complex concepts. Information visualization means to create a visual representation of abstract data to amplify cognition [15]. Visualization includes information graphics such as maps and charts as well as information design which is an effective way to communicate information through visual narratives within an illustrated context [16].

In the recent years, computer generated visualizations are increasingly used in sports to enhance viewer. Fans of all sports enjoy looking at stats for their favorite teams and players. Basketball is no exception. Fans from all around the world follow their favorite team and players and enjoy looking at different stats about them. Website of National Basketball League (NBA) [51] provides stats for all the players and teams and tools like [44] are built using those stats which fans can view and follow. Similarly, for wheelchair basketball, various teams and clubs provides stats for their players. Like the British Wheelchair Basketball association provides all the stats for their matches [73] for their fans to view.

Computer-generated visualizations play an important role in performance analysis of players during matches and training. Various systems have been created for visualization of sports data. In [17] authors have created a Glyph [18] based visualization, called Matchpad for the process of notational analysis in sports whereby the important events of a match are tagged by an analyst for post-match analysis. Matchpad was created for rugby but the concept can be applied to any sport.
NBA uses SportsVU Technology [42] to track every player and generates a lot of data with this tracking. Much of the data is freely available on NBA stats website [51]. Although it captures every movement of the players as well as the ball, there remains the challenge of how to effectively visualize the captured data. Some work has been done in this area [43, 44]. [43] introduced the concept of a ‘shot chart’ which revolutionized the analytics in NBA. Shot chart is a visual representation of a player’s shot performance displayed as a heat map. Figure 1 shows shot chart of Spread variable created for two players in a game. In [44], authors introduced a tool called Buckets which interactively and simultaneously compares multiple players’ visualizations as well as shows an overview of how the shooting behavior varies across the league. Figure 2 shows the visualizations available in the Buckets tool.

Figure 1. Shot chart (Source: [43])

Figure 2. Buckets
(Source: http://buckets.peterbeshai.com/app/#/playerView/201166_2015)

The main aim of the project is to design a low-cost solution which can measure the performance of players and teams. The other objective of the project is to create visualizations for analyzing the data pertaining to individual players and team. Court Vision can be used both by the coaches and players to analyze individual performances as well as for the whole team. It can also be used by the fans of the game to view the stats of their favorite players and team. Currently available systems are high in cost and require mammoth hardware stack [75] which makes them impractical for small teams and clubs. This project was intended to reduce the implementation cost and to make it more accessible to such teams. Court Vision is a technical design project which explores various ways to measure and improve player performance. Iterative design process was used during the development cycle where the various stages of design cycle, user research, ideation, prototyping and evaluation were carried out multiple times.
4. Design

4.1 Functional Requirements
Design of the system and user interface followed on from establishing the user requirements. Initial requirements of the project came from an under-graduate project done earlier this year [85]. My project was a logical extension of this piece of work, which gathered requirements from interviews and questionnaire surveys to develop initial user requirements of a system.

Primary user requirements that were synthesized as a result were:

- The coach/players should be able to analyze the game.
- The coach/player should be able to view performance matrices like total distance travelled by a player in a match, average speed of a player in a match, total baskets scored, position of players at any point in time etc.
- The coach/players should be able to access the system from smart phones to get different stats and player profile.
- User interface which displays all the available stats in a coherent way.

Players also mentioned some additional (good to have) features like:

- Integration with Fitbit.
- Monitor heart rate during a game or practice session.
- Monitor passes and shot accuracy.
- Get a count of calories burnt during a game or practice session.

Because the system would be displaying personal information about a user, it was important that some form of user authentication should also be added to it. Also, because the system would be used by wheelchair users, who might have limited hand dexterity, the user interface should be designed in a way that it is intuitive and easy to use and should allow user to navigate through it freely without a need for formal training.

As the coach and players should be able to analyze the game, there should be a way for them to view the match later. It should be also helpful if they can pause the game during analysis. These requirements became the basis of initial development of Court Vision.

4.2 Iterative Design Process
Iterative design process helps in expediting the development process and test the design quickly. Iteration is often considered to be an integral part of design process and is believed to be a natural feature of a designer’s competency [70]. Feedback from each of the different phases of design and development can be easily looped back into the next iteration. Figure 3 shows an iterative design process cycle. This cycle is usually repeated multiple times in the entire duration of the project. Although iterative design can be included in any phase of the design process including when you want to make improvements to an existing product, it is always advisable to include it during the initial phase of product development so that any major changes can be made during the initial development cycle.

An iterative design approach was taken during the design phase of Court Vision. An initial prototype was presented to a user group of wheelchair basketball coaches and players to get their feedback and those feedbacks were included into the system in next iteration of the design cycle. During the entire development, this process was repeated twice with the initial user requirements taken from the graduation project. Then in the ideation phase, initial sketches were made, and various approaches of implementation were considered.
Figure 3. Iterative design process

These included, creating a low-fidelity prototype with no database integration but it should contain all the user interface elements (Horizontal Prototype) or creating a high-fidelity prototype with limited functionality but with integration with database and other services (Vertical Prototype) Then an initial vertical prototype was created which was later evaluated with the user group. Based on their feedback, the entire cycle was repeated. Ideation and prototyping are again iterative processes in themselves (Green arrows in Figure 3) wherein different approaches were considered and feasibility of those approaches were evaluated. Further details about user evaluation and feedback are mentioned later in the “User evaluation” section.

4.3 Architecture Overview

UWB BLE (Ultra-Wide Band Bluetooth Low Energy) beacons are used for determining the precise location of players in Court Vision. These beacons use a process called time-of-flight two-way ranging [19] which ensures the beacons can measure the exact location of an object with inch-perfect precision [20]. Beacons register the location of a player once every 0.5 seconds and this location is saved in Estimote cloud. All the Estimote beacons are registered to an email address. User can create an Estimote cloud account using the same email address. This helps in managing the beacons as well as fetching the data from the beacons.

Court Vision reads the player’s co-ordinates from Estimote cloud and saves it locally in a relational database. Court Vision server exposes RESTful APIs [21] which Court Vision UI uses to fetch data and display to the user. Players can also view their Fitbit data in Court Vision. For this, the user’s Fitbit account should be integrated with Court Vision. Detailed steps about how to integrate Fitbit account with Court Vision is present in the Appendix section. An overview of architecture is shown in Figure 3.
Figure 3 shows three servers sending data to Court Vision application. They are, the Estimote cloud, PubNub server and Fitbit server. The “black” Bluetooth symbols around the court represent the beacons attached on the court while the “blue” symbols represent the players. As mentioned above, Estimote cloud saves players’ location co-ordinates and sends that data to Court Vision application using RESTful APIs [21]. Similarly, Fitbit APIs are used to get player’s fitness data. Although, the Fitbit data is not stored in the Court Vision database and the APIs are directly called from the UI, Figure 3 shows a connection between the Fitbit server and Court Vision application server. This is because Fitbit client ID is saved in Court Vision database and is mandatory to query the data from Fitbit server. Fitbit client ID is created by the user from Fitbit website and can be saved in Court Vision application from the user profile page. Further details about this process are mentioned in the Appendix section.

A Raspberry Pi is attached to a camera and is placed near the court to calculate the position of the ball. These co-ordinates are sent to a PubNub [69] cloud server. Details about the PubNub are mentioned in the next section. PubNub is a light weight publish subscribe framework which can be used to transmit data between clients and servers. PubNub is preferred over REST APIs here because Raspberry is not powerful enough to host REST APIs. Also, because PubNub uses publish/subscribe architecture, the client does
not need to constantly poll the server to fetch the data.

Once the data is stored in the Court Vision database, the web application can request it as per need to show the data to a user. The communication between the client and Court Vision server is again handled via REST APIs as shown in Figure 3. The user interface of Court Vision is developed using AngularJS [22] and Bootstrap [23] frameworks. The backend of the application was created in the Java Programming Language [24]. Java is a high-level programming language used extensively in software development [25].

4.4 Initial Sketches
During the ideation phase, I created some sketches to put my thoughts on paper. I came up with various designs. Most important components required on homepage were – an area to view player position during match (live view), statistics of current match and an option to select matches from a list. Figure 9 shows three different designs highlighting these three components.

Figure 9. Initial Sketches

4.5 Tracking
4.5.1 Player Tracking
Player Tracking is done by using Estimote BLE (Bluetooth Low Energy) location beacons. Multiple beacons are attached to the basketball court where they automatically map and create a floor plan. In this mapping phase, they calculate their relative positions with each other and overall dimension of the court. Once the mapping is done, the static beacons (attached to the court) can track and get the precise x and y co-ordinates of other moving beacons (attached to players’ wheelchairs) within the space. The mapping is done only once, and the same floor plan can be used later if the position of the beacons does not change.
4.5.2 Ball Tracking

Tracking the position of the ball was one of the important aspects of the project. Ball tracking would help in calculating the number of passes as well as showing it in the live game.

Ball Tracking is done using a Raspberry Pi camera. Single camera can determine the position of ball because the radius of the ball is known. The camera should be placed at a distance where it can capture the entire basketball court.

A Raspberry Pi camera V2 module has a Horizontal Field Of Vision (HFOV) of 62.2° [66]. Width of standard wheelchair basketball court is 28 meters. So, if the camera is placed at approximately 23.2 meters it will be able to capture the entire view of the court (Figure 4). The Vertical Field Of Vision (VFOV) of the raspberry pi camera is 48.8° [66], which means it can easily capture the top of the baskets, which is 3 meters.

Ball tracking consists of 2 different steps:

1. **Getting the distance of the ball from the camera** – To find the distance of the ball first the perceived focal length of the camera lens was found. Triangle similarity is then used to find the position of the ball. To find the perceived focal length, first the ball was placed at a known distance D from the camera and a picture of it was taken. Then, the apparent width of the object in pixels was measured (P). The perceived focal length of the camera was then found using the formula \( F = \frac{P \times D}{W} \), where W is the diameter of the ball. Once the perceived focal length of the lens was found, the same formula was applied to get the distance of the ball from the camera. The distance \( D' \) at any time now is, \( D' = \frac{F \times W}{P'} \). Here, \( P' \) is the width of the object which is calculated at any time instant. OpenCV [74] is used for finding the width of the object in pixels (\( P' \)).

\[
\tan (31.1) = \frac{14}{x}
\]

\( x \approx 23.2 \text{ m} \)

**Figure 4. Position of camera from court**

After calculating the ball position, these positions should be sent to Court Vision database which done using PubNub. Further details are described in next section, “Data capture”.

2. **Getting the angle of the ball from the center of the camera** – Trigonometry is used for calculating the angle of the ball from the center of the camera. Distance of the camera from the center of the court is already known. For every frame captured in the camera, the distance of the ball from the camera is determined, as described above. The angle between the center of the court and ball is calculated using OpenCV. Given these variables the angle between the camera and ball is calculated. Further details are described in the Appendix section.

**4.6 Data capture**

**Data from Estimote cloud** – Estimote exposes REST APIs to fetch data from the cloud [68] which provides beacons X and Y co-ordinates. Court Vision calls these APIs at regular intervals and
these co-ordinates are saved in the Court Vision database in form of Events. Further details about the database schema is present in the Appendix section.

**Data from ball tracking and baskets scored** – Ball tracking and counting number of baskets uses a Raspberry Pi and Arduino boards respectively which are not part of Estimote cloud. For fetching the data from both, Raspberry Pi and Arduino, PubNub [69] is used. PubNub is a real time publish subscribe framework. It offers the capability to transfer messages from publishers to subscribers in less than 0.25 seconds. As PubNub is a publish subscribe framework, objects from where the data is sent, Raspberry Pi and Arduino in this case, becomes the publisher. They publish the data to the PubNub cloud. Court Vision system is the subscriber that receives the data from PubNub cloud. PubNub offers push notification instead of polling, so that the subscriber doesn’t have to query the PubNub cloud at regular intervals. Instead the cloud APIs notify the subscriber whenever a new message is received.

Raspberry Pi and Arduino constantly publish data and Court Vision reads and saves it in the database from where it is further used.

**4.7 UI design principles**
As the users of the system are mainly wheelchair users who might have limited hand dexterity, it is important that the user interface is designed in a way that is intuitive and easy for the players and coaches to use. Following design principles were used throughout the design:

1. User should get feedback for every action [67].
2. There is sufficient spacing between the different controls of the system.
3. There is an option for the user to increase the font size.
4. Personalized data for coaches and players, so they don’t have to search for relevant details.
5. Use of consistent formatting for all displays [67].
6. Minimum user interaction so that there are minimal chances of error [67].
7. All the error messages should be appropriately displayed to user and wherever possible, there should be an option to recover from it.

Further details about these design principles are described in the “Implementation details” section.

**4.8 Initial high-fidelity prototype**
Once the initial sketches were created, I started working on an initial prototype. The idea was to create an initial version which can be shown to the user group to get some feedback early in the development cycle. This approach proved to be helpful as I got valuable feedback from the users which later helped in finalizing the features. The initial version contained limited features with options to create an account, view live games and track the position of players and ball at any point. I created dummy data for player and ball position for demonstration purposes. Results from the initial evaluation are presented in the next section “Initial Evaluation and User Testing”.

**4.9 Implementation details**
Instead of creating native mobile apps, the user Interface is created as a web application which renders perfectly in desktops as well as in mobile devices. This has tremendously decreased the overall development time and will reduced the maintenance effort.

The entire application is divided into various sections:

- **Login** – As Court-Vision contains personal information about players and coaches, all
users must first authenticate themselves before accessing other modules of the system. This also helps in showing personalized content to the user. Players would like to view their performance metrics first while coaches would like to focus more on team performance. Personalization helps in showing relevant content based on user profile, in this case coach and player. Personalization also impacts user’s decision-making stages [26] which can help coaches make fast decisions during a game. Figure 4 shows Court Vision login page.

- **Home** – Home page contains information about matches. It provides condensed stats like total baskets scored, top scorer in the game, game duration and pass accuracy about the current game. It also shows quarter specific stats like pass accuracy in different quarters. Figure 6 shows game stats available on home page. It also contains details about previous matches and links to move to other pages. One section of the home page will contain a view of the current match. User can select any previous game and it will display players’ movements over a period. User can also pause the game to analyze players’ positions. This will help the coaches to analyze the game in a better way. Figure 5 shows the live view of the court with player positions in real time. personalized information about that user.

- **Profile** – This page contains details about a player’s personal information like username, age, height, option to enable Fitbit integration, option to change password and option to request access other player’s data (more details on requesting access feature is present in the “Modifications” section).

- **Match details** – This page provides further details about the game. It provides a personalized view of data. For a player, it shows various visualizations stating the performance of the player in the match. These visualizations include, speed of player at any instant, average speed in the game, total distance travelled in the game. It also lists down the average speed of player and total distance travelled in different quarters of the game. If the player has enabled the Fitbit integration, this page will also show the heart rate of the player during the game as well as total calories burnt during the game. It also shows the position of player during the during in form of a heat map. Figure 7 shows a match details page for a player. This page also shows the overall player statistics like total distance travelled in the game, total baskets scored and average speed of the player in the game (Figure 9). A Coach could see all the above visualizations for all the players except for Fitbit data. Figure 8 shows match details page for a coach.

- **My Team** – This section is available to a coach only. This section is present towards the end of the home page. It lists down all the members of the team. Coach will have the option to go to an individual’s players profile from this page. If a player has requested access to view other player’s data, this page has the option for the coach to accept or reject his/her request. For more details about requesting access, please see “Modifications” section. Figure 17 shows My Team page.
Figure 4. Court Vision login page

Figure 5. Live position of players
Figure 6. Match specific stats (Pass accuracy in quarters, game duration, number of baskets)

Figure 7. Match stats (Player specific)
Figure 8. Match details (Coach view)
Unnecessary user interaction increases chances of error [67]. So, Court Vision is developed in a way to keep the user interaction to minimal level but still provide all the relevant details to the user. All the features are clearly segregated and defined in separate pages which makes it easier to navigate. Sufficient spacing is provided between all the controls to reduce the number of accidental clicks.

Every user must sign in to access Court Vision. This adds a level of security as well as helps in personalizing the content for the users. A player is usually concerned about his/her performance while a coach is interested in the performance of the entire team. Adding user roles and mandatory sign in helps in displaying personal and team specific data to player and coach respectively. Consistent formatting is used across all components to make the user interface look clean.

Initially, it was planned to add a search feature in the application. But later it was left out from the design because of three reasons:

1. Court Vision is not a data intensive application.
2. It could confuse users as to what he/she can search in it.
3. Search is hard to implement, and it was not feasible to implement in the given timelines.

When asked about if search would be an important feature in the application, one of the coaches said:

“It doesn’t look that it (search bar) is necessary here. Anyways [s]he can select a match from the list and view all the details [...]”

Ease of use is another important feature which was considered during the design of Court Vision. While viewing the games, user has the option to pause the game which makes it very convenient, especially for coaches when they want to analyze the game by checking the position of players with respect to ball at any instant. Another important feature is the option to view the game for any specific duration. The application provides a slider next to the live match window in which user can select any time duration and view the game only for that duration. This would help the coaches while analyzing the game.

4.10 Visualizations

One of the primary objectives of the project is to present the collected information to the coaches in an easy to understand way using different visualizations. Most of the visualizations created for this purpose are Cartesian graphs. These graphs are powerful because they not only allow the viewer to perceive the x and y values separately but, also provides the ability to understand the relationship between the 2 values [64]. For example, the graph in Figure 10 provides the comparison of the speeds to 2 players during a game. From this graph it is easy to get the speeds of a player at any instant but also to draw a comparison between the speeds of the 2 players. Similarly, Figure 11 is another Cartesian graph which shows the heart rate of a player during the game. Heart rate data is fetched from Fitbit APIs.

![Player Stats](image)
Figure 10. Comparison of Speeds of two players in a game

Figure 11. Heart Rate of player during different times in the game. Fetched from Fitbit

Figure 12. Heatmap of player’s position during the game
Heatmaps can be helpful in viewing certain kind of data. They can serve as illustrations of a user’s viewing behavior and distribution of attention. But they must be used cautiously as they communicate data but cannot explain or analyze it [65]. Heatmaps should always be accompanied with other analysis [65] which is done in Court Vision application. Heatmap of player position is shown in Figure 12. It gives the coach an indication of where the player is moving in the game which was one of the primary requirements that came up during initial evaluation phase of the project. This information is complemented by other information about the player like the total distance travelled and average and top speed of player in the game.

5. Initial Evaluation and User Testing

For the initial evaluation of the high-fidelity prototype, I met 2 coaches of a local wheelchair basketball team. During the conversation, I inquired about how they currently measure the performance of their players as well as asking them for feedback on the initial design. They mentioned that all the measurements are currently done manually. They use a mobile app called Basketball Stats Lite [63] where all the details should be added manually. During the game, one of the coaches would keep a track of all the passes made, baskets scored and add those to this app. They also mentioned that there is always a chance of error in this process and there is no way to avoid it. One of the features which they liked in this app was the option to export all the data in an excel sheet which they email to all the players after the game. Players can then analyze their performance in the game by checking this sheet. Figure 13 shows are sample data sheet.

Both the coaches really liked the idea of Court Vision. They were excited to see the features of the initial prototype. Some of the comments from the coaches were:

“[...] This will be really helpful for analyzing the performance. What I really liked is the option to view the entire game later. Option to pause the game is really cool.” – Coach 1.

“Currently we use beep test to measure the top speed of a player, which is not very accurate as it is measured only for a short distance. If we can get the top speed and average speed of player in a game, that would really help [...]” – Coach 2.

They also pointed out some potential issues and provided some feedback on how to rectify those issues.

- Initially, all the players were able to see other player’s data. As per the coaches, this could create some issues especially when the team loses a game with a minor difference.

“I can see that the views are similar for the coach and players. Only a coach should be able to view other player’s data. A player should only view his own data. Otherwise players tend to pick on a particular player if he/she did not perform well in a match and we lost that match with a minor difference.” – Coach 1.
There was no concept of different teams in the initial prototype. So effectively there will be only one team in the system. This would mean that only players from one team can be tracked in the game. To cater this requirement, a concept of different teams should be introduced.

- During signup only one person should be able to create an account as a coach. Others can only signup as players.
- Users can request permission to view other player’s data and it is on the discretion of coach whether he/she wants to allow that.
- If possible, there should be an option to export data as an excel sheet as our players are used to reading stats from an excel sheet.

After getting the above feedback, second cycle of iterative design process (Figure 3) started where all the feedback items were thought of and their feasibility were evaluated. Because the first 4 items were the limitations of the current prototype and the last one was an enhancement, I decided to work first on the limitations in the next iteration of Court Vision. Further details about the changes are mentioned in the “Modifications” section.

I also interviewed 3 wheelchair basketball players, one of whom was the captain of the team. I got similar feedback as I got from the coaches. They were excited to see the option to view the game later as well as the feature to pause it.
“[...] It would be helpful to watch the match afterwards [...]” - Player 1

“It would be very helpful to watch the game afterwards. So, if a referee called a foul, you can always go back and see why that happened [...]” – Player 2

When asked about the features they would like to see in the application, one of the players mentioned a way to get the energy levels during the game, which she later clarified as speed of player at different times of the game.

“Energy levels, [...] change in speed of players at different duration. So, between start of the game to versus the end of the game.” – Player 1

Almost, everyone also mentioned that these metrics should not be limited to a game, but they should be able to track these numbers over a period, like a season.

“These (metrics) are important for over a period of games like in a season.” – Player 2

6. Modifications

Based on initial feedback of the coaches, the signup process was modified. Concept of different teams was introduced in the system. Now during the registration process, user must select his/her team from a dropdown. Then the user can fill in his/her details and check a checkbox if he/she wants to register as a coach. Only one user from a team can register as a coach. Once a coach is registered for a team, the checkbox is disabled and all other users for the team will be registered as players. Figure 14 shows the signup page. Based on user profile as coach or player, he/she can see different views in the application.

Because now the players can ask for permission to view other player’s data, there should be a way to notify the coach when such requests come. For this purpose, the concept of notifications was also introduced in the second version of prototype. When a player raises a request, a notification is sent to the coach which he/she can see in the notifications (bell icon) in the header of Court Vision (Figure 16). Players can request access to view the entire data. He/she can do this from the profile’s page by simply clicking request access button. Figure 15 shows the player’s profile page with request access button. Once the player has requested access, a notification is sent to the coach and he/she decide whether to grant access or not. Figure 16 shows a notification received to coach to grant access to a player to view other player’s data. The coach can grant access to a player from my-team page. He/she can see all the requests on that page and can selectively decide to give access to specific users. Figure 17 shows the “My Team” section. Once the access is provided the player will effectively become a coach in Court Vision.

7. Final evaluation

Once these features were implemented, the second version was shown to the coaches and players. This was a discussion within a group rather than individual interviews. They were excited to see the new features and gave some good feedback. When asked about the new signup process, Coach 1 said:

“[...] This looks great. This is exactly what I was talking about last time [...]” – Coach 1

But one of the players mentioned that the current way to signing up as coach is not very secure and anyone can go and signup as a coach if the team coach has already not registered on the system. This turned out to be a genuine problem and everyone else agreed to it. She also suggested that there should be a centralized authentication system where the passwords to coaches should be sent, rather than they creating the passwords themselves so that proper check can be kept about the authenticity.
Figure 14. Signup page

Figure 15. User can request access from profile page
No changes are made around this after the feedback. This can be considered as a future work as there are a few open questions around this approach, like, how to check if the first-person registering is the coach. Additional work will be needed for integrating the Court Vision with SMTP server to send out system generated passwords as emails. One of the suggestions which came up during the discussion was to make sure that the first person to register in the system for a team is the head coach.

The users also liked the idea of using notifications. This will let the coaches know if they have any pending requests as soon as they login, rather than going to the “My Team” page.

“[…] I like the bell icon. I hope it will show me the notifications […]” – Coach 2

As the part of discussion, users were asked if they can understand the visualizations created for a match. As they are created as Cartesian graphs, they looked familiar to the users and they were able to decode them easily. They especially liked that the some of the visualizations were presenting quarter specific data which would be useful. As Player 1 suggested about the energy levels in the previous interviews, when asked about these graphs, she said:

“Yes, this would help in understanding the energy levels during the game. Now I can see my speeds in different quarters.” – Player 1

8. Discussion

Primary objective of this project was to help the coaches and players of wheelchair basketball teams to monitor and improve their performance with time. This was done by creating a high-fidelity prototype called “Court Vision”. It will cater to all the requirements of the players and coaches which were initially identified. Although there are already several systems available for this purpose in the market [41, 42], which are used in professional sports, none of them were created specifically for wheelchair basketball and are mostly used in non-wheelchair Basketball and Soccer. Court Vision is designed specifically for wheelchair basketball players which provides additional features like integration with Fitbit which was one of the initial requirements. One of the biggest advantages of Court Vision is that it is a low-cost system compared to other software available which is very important to local clubs and teams. Although, the cost of professional systems varies on the features users opt for and
it is not readily available online, typical cost of the basic version could be around $12000 per season [93]. Court Vision would cost less than 10% of this value. Most of the professional systems use computer vision techniques for tracking which makes them expensive as they require high computing power for processing. Court Vision, on the other hand, uses low energy BLE beacons and a Raspberry Pi powered camera which significantly reduces the computing power. Entire Court Vision application can easily run on a laptop or on a free cloud service which makes it an ideal low-cost substitute.

Chairables was a concept introduced in [76] and later prototypes for the same were created [79, 86]. In Chairables, various sensors were attached to the wheelchair to calculate a variety of trackable metrics. SpokeSense [76] is one such prototype which uses different kinds of sensors to measure various metrics like speed, acceleration and distance travelled for a player during a game. Court Vision extends the idea of Chairables where by attaching sensors to wheelchairs as well as in the court, it is capable of tracking players in real time. Court Vision can also be used by coaches to analyze the game by viewing the positions of players at any instant during the game. Coaches also have an option to pause the game to take a closer look at the player’s positions at any instant.

Currently, Court Vision uses Bluetooth beacons for tracking players. But, it is designed in a way that the user interface is independent of the tracking logic. So, Court Vision user interface can be a complement to the work done in [82] and [83] providing a user interface for coaches and players to view the tracking data. Court Vision also handles the data privacy issues in a unique way wherein initially only the coach will have the access to view the data of all the players, but there is an option for a player to request access to entire data. So, in Court Vision there is an option to restrict the data view as well as to share it across all players. This will address the concerns raised in [86].

Court Vision tracks multiple players at a time in a game. This creates an opportunity to explore the team dynamics of players in the game. Game mechanics and dynamics are frequently studied together and can contribute to performance measurement [88]. [89] defines game mechanics as a set of components of the game including the elements and rules of the game while game dynamics is defined as the run-time behavior of the mechanics acting on player’s inputs and outputs over time. Studies [90] have shown that ball passing networks and positioning variables can be linked to the match outcome. Notational analysis, like determining number of shots and successful passes, can also be a powerful framework to produce valid and reliable description of team’s performance [91, 92]. Court Vision is a tool which can help the coaches in determining these variables and in turn will help in performance improvement.

9. Limitations
Court Vision uses Estimote Beacons for player tracking. These beacons must be calibrated initially. During the calibration phase, they generate a floor map of the area in which they were installed. Due to some technical issues, the calibration phase did not work. Because of time constraints and lack of technical support from the Estimote team, I was not able to explore the root cause of the issue. Because of this, the player tracking did not work as intended. It would need some more exploration and help from Estimote team for it to work. But Court Vision is designed in a way that the tracking logic is loosely coupled with the user interface. So, if the issue with the Estimote beacons persist, additional methods for tracking players can be explored and the data can be fed to the Court Vision database. The user interface would work seamlessly without making any changes.
In wheelchair basketball, points are calculated based on from where the ball is shot into the basket. Currently, in Court Vision, all the points are calculated as a single value. It cannot differentiate between 2-point shot and a 3-point shot. This can be differentiated by checking the player’s position in the court when the ball was shot into the basket but because the player’s tracking is not working as expected, no further work was done in this area.

10. Conclusion and Further work

This project was intended to provide a low-cost solution for the coaches and players of wheelchair basketball teams to help them improve their performance. Court Vision does this by providing various performance metrics like the total distance travelled, average and top speed of players in the game, position of players and pass accuracy. It is also capable of providing quarter specific data which is important to determine the energy levels of players. A user interface was created for the coaches and players to view this data. The data is presented in easy to understand visualizations which makes it intuitive. It has additional features like integration with Fitbit which helps them to track their body stats like heart rate and number of calories burnt during the game.

Because of time constraints, some of the features, like player tracking did not work as expected. There were some technical issues in the initial calibration phase of Estimote beacons and because of time constraints and lack of technical support from Estimote team, the work on tracking players could not complete. Some additional effort would be needed to make the tracking work as expected. Other techniques like computer vision and Neural networks can also be explored for tracking players in the court.

Court Vision user interface does not currently support keyboard accessibility. It was not considered during the design as it was assumed that the players and coaches would be comfortable using a mouse. No feedback was provided by the users around this limitation during the user testing as well. But keyboard accessibility could be an important feature for some of the users and should be considered as a requirement for future development. Future work should also include making the user interface fully accessibility compliant.

During the first iteration of user testing, one of the coaches also requested a feature to export the data of a match to an excel sheet which the players of the team can use for analysis. Further exploration is needed to see if this could be helpful to other teams as well. Court Vision should also be tested with other teams to see if other visualizations could be added to make it more versatile.

Another limitation that was brought up during the user evaluation phase was coach signup. In the current signup process, there is a check box which a coach can check, and it will assign him/her coach user role for a team. All the users registering after that would have player user role, by default. Currently, there is no way to knowing if the first user registering in the application is a coach or not and a player has the option to register as coach if a coach has already not registered for that team. It would need some further exploration so that this entire process can be streamlined.

Fans of all sports enjoy looking at stats for their favorite teams and players. Currently, Court Vision is only meant for the coaches and players. It can be further extended to viewers and fans as well so that they can also view the stats of their favorite players and teams. This would require additional user research because some of the stats currently available to players and coaches might not be relevant to the viewers. So, another
user role like “viewer” or “fan” should be created and the content should be personalized accordingly. If Court Vision is deployed as a single cloud instance, where all the teams can register, a concept of ratings can also be introduced which will be of interest to the viewers.

Game dynamics is another area which can be further explored by using Court Vision. Although, Court Vision can be used to understand the basic team dynamics, further interactions with the coaches and players are needed to understand how it can be further improved.

It is hoped that with these further improvements, Court Vision would become a complete solution for local teams and that it would help the players and coaches to improve the performance of the team.

11. Appendix

11.1 Technical Implementation Details
Entire code of the project is available on Github at: [https://github.com/ayush04/court-vision](https://github.com/ayush04/court-vision)

11.1.1 Ball Tracking
As mentioned in 4.5.2, ball tracking involved 2 steps, first, to find the distance of the ball from the camera and second, find the angle between the camera and the ball. Figure 18 shows the position of ball and camera. Here, c is the camera, b is the center of the ball and o is the center of the court. Distance D and L and angle α is known.

By using Trigonometry, we can find the value of β.

![Figure 18. Ball position](image)

11.1.2 Baskets scored
For calculating the number of baskets scored, HC-SR04 ultrasonic sensor [94] is used. It calculates the distance of an object by constantly transmitting ultrasonic waves and registering the time of return of these waves when they reflect from the object. An HC-SR04 sensor was attached to an Arduino board and the entire setup was put towards the end of the hoop. The distance calculated by the ultrasonic sensor was then checked against a threshold score. If the distance was below the threshold value, then it means that the ball has passed the hoop. This method is not very efficient because it is possible that the ball can directly hit the sensor without passing from the hoop. This is a limitation and should be investigated in future work. Whenever a basket is scored, the timestamp of the basket is registered. This data is then manually transmitted to Court Vision. Due to time constraints, I took code from [95] as reference.
11.1.3 Court-Vision system

Court Vision is created with an aim to provide the much-needed quantifiable data to the coaches and players of the wheel chair basketball which can assist them to improve the overall performance of the players.

The technology stack used in the implementation of the Court-Vision is:

1. AngularJS – An open-source JavaScript framework front-end web application development [22].
2. Bootstrap – A free and open-source framework for designing web applications [23].
3. Java Programming Language [24].
4. Hibernate – Object Relational Mapping (ORM) tool for Java Programming language. It provides a framework for mapping an object-oriented domain model to a relational database [52].
5. Apache Derby – An open-source relational database management system (RDBMS) [53].
6. REST APIs – Representational State Transfer APIs used for creating web services [54].
9. Google Charts – For creating interactive charts [57].
10. Fitbit APIs for Fitbit integration [58].

11.1.3.1 Server-Side Implementation

Server-side implementation is done using Java with Apache derby as the relational database. Hibernate is used as an ORM to make the code independent of database. This means that the entire application can be migrated to a different database without changing a single line of code. Only the database connection details should be changed in the hibernate properties file.

11.1.3.2 Database structure

There are 14 tables present in the application. Figure 17 shows the table schema along with their relationship with each other.

Complete database schema is available on Github along with the code.

Player / Ball co-ordinates – Positions of objects are stored as events in the system. EVENTS table stores all the data related to player’s and ball’s movements. Events are categorized into various types details of which are stored in EVENT_TYPES table. Various events are:

MATCH_START_EVENT_TYPE = 1
MATCH_END_EVENT_TYPE = 2
BASKET_SCORED_EVENT_TYPE = 3
PLAYER_POSITION_EVENT_TYPE = 4
BALL_POSITION_EVENT_TYPE = 5
QUARTER_END_EVENT_TYPE = 6
USER_ROLE_CHANGED_TO_COACH = 7

For every movement of the player an entry is made in the events table with event type 4. Similarly, for every movement of the ball, an entry is made with event type 5. X and Y co-ordinates of the object being tracked are saved with this entry.

11.1.3.3 Business logic

Every table is mapped to a data-object. Java code only interacts with these data-objects. It is the responsibility of Hibernate to update the data from these data-objects to the database. Business logic contains methods to calculate various metrics for the user to view.

Calculation of key metrics – To calculate the total distance travelled by a player in a game, distance between every 2 consecutive points is
calculated and added together. To calculate the average speed, total distance cannot be just divided by the duration of game because the game duration will include the half time and quarter breaks. This time duration should not include any time when the players were not playing such as during quarter breaks and half time. It is also possible that a player is replaced by another player during the game, so these events should be excluded when calculating the average speed of player. To calculate the actual time duration when the player played in the game, number of position events are calculated and multiplied by 2 as player position events are recorded every 2 seconds. Figure 16 shows the code snippet for calculating the average speed of player in game.

To calculate speed of a player at any point of time, the distance between 2 consecutive points are calculated and then divided by the time difference between the two events. Figure 15 shows the code snippet for calculating the average speed of player in a game.

Similarly, Figure 16 shows the code snippet for getting the total number of passes and successful passes in a game. Using these two values, pass accuracy is calculated.

```java
public static double getAverageSpeedOfPlayerInGame(long userId, long gameId) {
    double distance = 0;
    List<EventsData> playerEvents = EventsService.getPlayerPositions(userId, gameId);
    EventsData initialEvent = playerEvents.get(0);
    for (int i = 1; i < playerEvents.size(); i++) {
        distance += distance(Double.parseDouble(initialEvent.getEventValue()),
                              Double.parseDouble(playerEvents.get(i).getEventValue()),
                              Double.parseDouble(playerEvents.get(i).getEventValue()));
        initialEvent = playerEvents.get(i);
    }
    return distance==0 ? 0 : (distance/(playerEvents.size() * 2)) * 1000;
}

private static double distance(double x1, double y1, double x2, double y2) {
    return Math.sqrt(Math.pow((x2 - x1), 2) + Math.pow((y2 - y1), 2));
}
```

**Figure 15. Calculation of average speed and distance travelled by player**
Figure 16. Calculation of total number of passes and successful passes

```java
public static int[] getNumberOfPasses(long gameId) {
    int numberOfPasses = 0;
    int successfulPasses = 0;
    long currentPlayerId = -1;
    Double[] previousBallCoordinates = null;
    HashMap<Long, List<Double[][]>> map = new HashMap<>();
    long[] playerIds = MappingsService.getPlayersInAGame(gameId);
    for(int i=0; i < playerIds.length; i++) {
        List<Occurrences> positions = EventsService.getPlayerPositions(playerIds[i], gameId);
        map = insertPositions(positions, map);
    }
    map = insertPositions(EventsService.getBallPositions(gameId), map);
    for(Map.Entry<Long, List<Double[][]>> entry : map.entrySet()) {
        List<Double[]> positionList = entry.getValue();
        Double[] ballCoordinates = positionList.get(playerIds.length);
        for(int i=0; i < playerIds.length; i++) {
            if(Object.equals(positionList.get(i)[0], ballCoordinates[0])
                && Object.equals(positionList.get(i)[1], ballCoordinates[1])) {
                if(currentPlayerId != -1 && currentPlayerId != i) {
                    numberOfPasses++;
                }
            }
            if(previousBallCoordinates != null) {
                if(!Object.equals(previousBallCoordinates[0], ballCoordinates[0])
                    || !Object.equals(previousBallCoordinates[1], ballCoordinates[1])) {
                    numberOfPasses++;
                }
            } else {
                previousBallCoordinates = ballCoordinates;
            }
            currentPlayerId = i;
        }
    }
    return new int[]{numberOfPasses, successfulPasses};
}
```
Figure 17. Database schema
11.1.3.4 REST APIs
REST APIs are endpoints resolving to unique URIs which can be called by client to fetch or update the data in application. The application exposes various such REST APIs. Every API performs a specific task and are independent of each other. This approach is helpful because now the client-side code becomes independent of the server-side code. There is no hard-coupling between the two. This principle is called Separation of Concerns (SoC) [59]. All the APIs, except for few are authenticated APIs and requires a valid session ID. The login API returns a session ID after successful authentication and all the subsequent API calls in that session should pass that session ID in the request.

11.1.3.5 Client-Side Implementation
AngularJS and Bootstrap are used as the frameworks to develop the frontend of the system. Bootstrap helps in creating responsive layouts for the application which makes it usable on all screen sizes without writing additional code. AngularJS is JavaScript framework used for developing applications with Model-View-Controller (MVC) architecture [60].

The front-end of the application is divided into various pages. Each page represents a different view on the browser. These pages are:

- Login
- Signup
- Home
- Match details
- User profile

Each page is divided into one or more reusable elements called components. Each component represents an independent element on a page like header or side-bar. All the components are independent of each other and can be used in any of the pages except for Login and Signup pages as the APIs used in these components are authenticated and must contain a valid session ID. This approach has helped immensely in the development process because it becomes very easy to try out various layouts of the application without changing any code.

Figure 18 contains the folder structure of various pages and components.

![Figure 18. Court Vision folder structure (Netbeans Project)](image)

11.1.3.6 Fitbit Integration
Court Vision can connect to Fitbit APIs to fetch personal data. This data will be personal to individual users only and coaches also won’t be able to view it. There is no option to allow access to Fitbit data to anyone else. Integration with Fitbit is a two-step process:
1. Create a Fitbit account and register an app – 
   This is a very simple process where the user first needs to first create a Fitbit account from [https://www.fitbit.com/uk/signup](https://www.fitbit.com/uk/signup). Once the account has been created he/she needs to register an app with Fitbit. Registering an app is a straightforward process where he/she needs to fill a simple form. This can be done from the URL - [https://dev.fitbit.com/apps/new](https://dev.fitbit.com/apps/new). Sample app form is shown in Figure 19. Important thing to keep in mind is to select OAuth 2.0 Application Type as **Personal**, callback URL should be [http://<SERVER_URL>/cv/components/fitbit/fitbit-success.html](http://<SERVER_URL>/cv/components/fitbit/fitbit-success.html) where <SERVER_URL> is the web server URL of the deployment and Default Access Type should be **Read-Only** as shown in Figure 19. Once the app is registered, Fitbit will provide a OAuth 2.0 Client ID. Figure 20 shows the app credentials page with OAuth 2.0 Client ID on top. Copy this Client ID and paste it to the Fitbit Client ID field of profile page of Court Vision (See Figure 15). Once added, save the profile.

2. In the header of Court Vision, click on the Fitbit link (See Figure 21). This will launch the Fitbit login page, asking you to login. After successful login, it will ask you to allow access to the Fitbit app created in step one. Please select Allow All checkbox and click on Allow button. Default access is provided for 1 day. This is increased to 1 year from the dropdown on top (Figure 22). After clicking on allow, the user will be redirected to a success page (Figure 23). This means the authentication is successful and user can close this window. This is a one-time configuration and is not needed for every access.

![Figure 19. Fitbit app creation form](image1.png)

![Figure 20. App details page](image2.png)
After successful authentication, user can see Fitbit data visualizations on the graph page like the heart rate visualization (Figure 11).
12. References

2. https://iwbf.org/about-us/who-we-are/
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