Technical and Tactical Analysis in Fencing: A Review of Current Visualization Technologies

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***Abstract*—Fencing, a sport rich in history and strategic depth, presents unique challenges for data analysis. Despite its complexity, traditional visualization tools often fall short in capturing the intricate dynamics of fencing. This paper takes a closer look at the limitations of these tools and explores innovative visualization techniques from other sports that could be adapted to better analyze fencing techniques and strategies. Deep learning technologies hold particular promise for fencing analysis. Leveraging these advanced tools could uncover new insights and enhance our understanding of the sport. The potential benefits are significant, with improved visualization and analysis capabilities poised to revolutionize the way fencers and coaches train and compete. This review highlights the pressing need for tailored visualization solutions that can keep pace with the demands of fencing. By developing more effective analytical tools, we can empower fencers and coaches to make data-driven decisions, optimize their performance, and gain a competitive edge.**

***Keywords*—fencing analysis, visualization, deep learning, data-driven decisions, performance optimization**

I. Introduction

Fencing, often heralded as "the sport of the sword," combines the elegance of ancient combat with the precision and agility of modern athletics. This discipline is distinguished by its three main weapons: the foil, the sabre, and the épée, with the foil being the primary choice for most fencers, especially beginners. The sport has a rich history, tracing back to the duels of honor in centuries past, and has evolved to become a staple in the modern Olympic Games [1], showcasing its enduring appeal and competitive spirit. At its core, fencing is a dynamic interplay of mind and body, frequently likened to "physical chess" for the strategic depth it demands. Participants quickly learn that physical strength alone does not guarantee victory; instead, intellect, strategy, and finesse are equally vital [2]. The sport offers an engaging blend of high-intensity bouts and strategic pauses, where fencers vie to outmaneuver their opponents through rapid, skillful movements aimed at striking the opponent's target area.

The rules of fencing are straightforward yet intricate, emphasizing honor, skill, and strategy. Each match, or "bout," commences with a salute between competitors and the referee, setting the tone for the respectful and disciplined nature of the sport. The objective is to score points by landing hits on the opponent's designated target area with one's sword [3]. Bouts are divided into three periods of three minutes each or until one fencer reaches 15 points. Movement on the piste, or fencing strip, is a tactical dance, with each fencer employing a mix of offensive and defensive maneuvers to score points or deflect the opponent's attacks.

Scoring in fencing is nuanced, governed by a sophisticated set of rules that emphasize not just the act of striking but the strategic execution behind each movement. This highlights why technical and tactical analysis is indispensable for fencers and coaches alike. Mastery over the sport extends beyond physical training to include a deep understanding of fencing's strategic components. Coaches and athletes must dissect each encounter, analyzing movements, decisions, and outcomes to refine techniques and develop smarter game plans. This analysis is not just about recognizing what actions were successful but understanding why they worked, the context of each bout, and how similar tactics can be applied or countered in future matches.

The development of an athlete's technical skills—such as the precise control needed for effective parries and ripostes, and the tactical acumen to choose the right moment for an attack—becomes a focal point of training. Similarly, tactical analysis involves studying opponents' styles, identifying patterns in their strategies, and crafting countermeasures that exploit their weaknesses while bolstering one's own defensive and offensive maneuvers. The ability to analyze one's own performance and that of opponents through a technical and tactical lens is not just beneficial; it is essential for advancement and success in the highly competitive arena of fencing. This analytical approach not only enhances individual performance but also elevates the sport as a whole, as coaches and athletes push the boundaries of what is possible within the art and science of fencing.

The integration of visualization technologies into fencing analysis highlights a critical need for innovation tailored to the sport's unique characteristics. Traditional visualization methods, while effective for team sports like soccer and basketball [4, 5], fall short in addressing the complexities of fencing. Characterized by rapid, strategic exchanges, fencing generates complex time-series data that captures the nuanced interactions between competitors. This data requires bespoke visualization tools capable of illustrating fencing's intricate tactical sequences and technical maneuvers, a challenge yet to be adequately met by existing methodologies. Furthermore, the sport's hierarchical action structures and the depth of strategic engagements are not effectively captured by standard visualization approaches, leaving the rich tactical patterns—essential for comprehending fencing's competitive dynamics—largely obscured.

Therefore, reviewing and understanding the current visualization technologies used in fencing is imperative. This review aims to shed light on existing tools, their applications, and their effectiveness in capturing the sport's complex dynamics. By examining the strengths and limitations of these technologies, we can better appreciate the advancements in the field and identify areas where further

innovation is needed to enhance the analytical capacity of fencers and coaches.

II. Fencing Sport

A. Technical Aspects of Fencing

Fencing is a sport that demands a blend of physical agility, precision, and strategic thinking. The technical aspects of fencing primarily involve footwork, bladework, and the correct handling of the weapon [1].

1. Footwork Actions: Effective footwork is foundational to good bladework [1]. The En Garde position is the readiness stance, crucial for all subsequent movements. Moving forward and backward requires balance and small, controlled steps. Overstepping can lead to a loss of stability. The largest step should be no more than a foot's length, emphasizing multiple small steps for balance.

a. The Lunge and Recovery: The lunge is a primary attacking move where the fencer pushes off the back leg, extending the front leg forward with power. Recovery is crucial as it allows the fencer to return to a safe distance if the attack fails, maintaining readiness for the next action. Proper execution involves kicking forward with the front foot and pushing hard with the back foot, ensuring a perfect lunge position.

b. The Flèche Attack: An aggressive, surprise attack involving a forward leap. The fencer leans forward over the front foot, with the thrust initiated from the front foot once the rear leg has crossed past the front. This attack aims to catch the opponent off guard, utilizing speed and surprise to score.

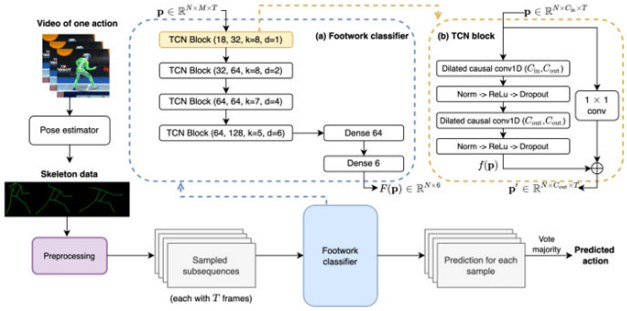

Fig. 1. The interface of the Fencing Vis [6].

2. Holding the Foil: The correct grip is essential for precision. The thumb sits on top of the handle, with the other fingers wrapped around it, ensuring the foil is an extension of the arm. The pommel at the end of the handle should align with the wrist, enabling accurate and controlled hits. A common fault is a tight grip, which can cause the pommel to drop below the wrist, leading to imprecise hits.

3. The Direct Attack: This involves extending the sword arm followed by a lunge. Timing is critical; the arm must lead to ensure the right of way. The direct attack relies on the strength and speed of the lunge and good footwork to get within the opponent's reaction time. Proper form includes extending the arm first, keeping the body upright, and ensuring the hand finishes higher than the point of the foil.

4. The Parry-Riposte: This defensive maneuver involves blocking an attack (parry) and immediately counter-attacking (riposte) [7]. Effective execution requires good distance control. The defender must be close enough to parry without getting hit but not too far to miss the riposte. Maintaining the right of way during this maneuver is crucial; any delay between the parry and riposte can result in losing the opportunity to score.

a. The Lateral Parry of Quarte: This is the simplest type of parry, moving the foil from the position of sixte in the high line to quarte in the high line. It is essential that the sixte position is correct to prevent the attacker from exploiting openings on either side of the defender's blade.

b. The Counter-Riposte: Involves a series of parry-ripostes, where the distance and timing are critical. The first counter-riposte must be well-timed to hit as the defender ripostes. Subsequent counter-ripostes require increasing speed to stay ahead of the opponent's reactions.

5. Preparations of Attack: Actions such as the beat and the engagement of sixte prepare the way for an attack by deflecting or provoking a reaction from the opponent.

a. The Beat: A sharp knock to the opponent's blade to deflect it, setting up for an attack. The beat attack is a combination of the preparation (beat) and the direct attack, where the arm must precede the foot after the beat to ensure proper timing.

b. The Engagement of Sixte: Holding the opponent's blade using the fingers to feel their tension and prepare for an attack. This requires a sense of sentiment de fer, where the fencer feels the opponent's blade to gauge their tension and readiness.

6. The Indirect Attack: These follow preparations and involve deceptive movements like the disengage to bypass the opponent's blade.

c. The Beat Disengage Attack: Involves making a beat followed by a disengage, where the fencer drops the point of the foil under the opponent's blade and returns it on the other side, then extends the arm and lunges. Timing is crucial, with the beat done as the front foot hits the floor.

d. The Cut-Over Attack: Similar to the disengage but passing over the opponent's blade. It is used against lower-held blades, where the fencer pulls the wrist back and moves over the opponent's blade.

7. Indirect and Compound Ripostes and Counter-Ripostes: These involve complex sequences of parries and ripostes, relying on timing and precision. Indirect actions like disengages are designed to deceive the opponent's parry. Compound actions involve multiple blade movements, including feints, to mislead the opponent.

8. Deception and Defense Against Deception: Deceptive tactics, including compound attacks, require skill to execute and defend against. They involve feints and multiple blade movements to confuse the opponent. Effective defense against compound attacks involves varying defensive patterns and maintaining good distance control to anticipate and counter the attacker's moves.

e. Compound Attacks: Composed of two or more blade movements, one of which is a feint. These attacks require an accelerating lunge to sell the dummy to the defender and must be executed from full lunging distance to maintain the right of way.

f. Defense Against Compound Attacks: Involves

varying defensive patterns using lateral, circular, and semicircular parries to make it difficult for the attacker to read and predict defensive moves. Good distance control is crucial to place effective parries and ripostes.

B. Tactical Aspects of Fencing

Fencing tactics are essential for applying technical skills effectively against an opponent during a bout [8]. Here, we outline key tactical elements involved in fencing:

1. Attacking on the Opponent's Preparation:

a. The Beat Attack on the Opponent's Preparation: This tactic involves using a beat followed by a direct attack as the opponent prepares to attack. Timing is crucial; the attack should be initiated as the opponent steps forward, ideally when their front foot hits the floor. This catches the opponent mid-step, making it difficult for them to parry.

Main Points: Timing and distance are fundamental. The attack must be well-timed and within the appropriate distance to prevent the opponent from reacting and parrying. This tactic exploits the opponent's focus on attacking, catching them off-guard and unprepared for defense.

b. The Counter-Disengage Attack: This is executed when the opponent attempts to engage your blade in the sixte position. By counter-disengaging, you can attack during their preparation phase, exploiting the moment they are focused on attacking rather than defending.

Main Points: The attack must be well-timed and executed from the correct distance to ensure the opponent has no time to react. This tactic takes advantage of the opponent's focus on engaging the blade, making them vulnerable.

2. Inviting Attacks and Second Intention Actions:

a. Inviting Attacks: This involves stepping forward to provoke an attack, then parrying and scoring with a riposte. The invitation must be convincing to draw the opponent into attacking.

Main Points: Successful execution requires a clear understanding of the opponent's lunging distance and attack power. The initial step must convincingly invite the attack, and the parry-riposte must be quick and well-timed.

b. Invitation with Step Forward and Engagement of Sixte: Combining footwork and bladework, the fencer steps forward and engages the opponent's blade in sixte, inviting an attack to set up a parry-riposte.

Main Points: The invitations must be convincing and well-practiced. The fencer's actions should appear as genuine preparations for an attack to draw a response from the opponent.

c. Second Intention: This premeditated tactic involves making an initial action to draw a specific response from the opponent, then scoring off that reaction. A common example is the first counter-riposte, where the initial attack is intended to provoke a parry, followed by a counter-riposte to score.

Main Points: The initial action must convincingly draw the desired response, and the follow-up must be executed without delay. This tactic requires premeditation and precise timing to be effective.

3. How Distance Governs the Choice of Attack:

a. Simple Attacks: Effective when the distance is close enough for the attack to land before the opponent can parry. Simple attacks rely on speed and surprise.

Main Points: Understanding different distances (riposte, lunging, step-lunge) is crucial for choosing the appropriate attack. Simple attacks require close distance, good timing, and often rely on the element of surprise.

b. Compound Attacks: Used when the distance is too great for a simple attack to succeed. Compound attacks involve multiple blade movements, including feints, to deceive the opponent.

Main Points: When simple attacks are not feasible due to distance, compound attacks offer an effective alternative by using deception. Proper execution requires understanding the appropriate distance and precise timing of each movement.

4. Close-Quarter Fencing:

a. Close-Quarter Techniques: Involves fencing at a very short distance, such as when both fencers lunge together or during a flèche. Techniques include using the four pronated garde positions: tierce, quinte, seconde, and prime.

Main Points: Close-quarter fencing requires regular practice to master the pronated positions and angulated actions. Being proficient in close-quarters adds another dimension to a fencer's tactical repertoire, allowing them to exploit situations where the opponent is less comfortable.

b. Parries of Prime, Seconde, and Tierce: These are used against strong, forceful attacks in close distance. Angulated actions, like hitting on the shoulder or back, are effective in these situations.

Main Points: Practicing close-quarter techniques regularly ensures they become a reliable part of the fencer's skill set. These techniques are particularly useful against opponents who excel at close-range combat.

5. Left-Handed Fencing:

a. Fencers must adapt their tactics when facing left-handed opponents, who often present different challenges and angles of attack. Observing and understanding the tendencies of left-handed fencers is crucial for effective tactical planning.

Main Points: Left-handed fencers require specific tactical adjustments. Observing their tendencies and adapting your strategy accordingly can provide a significant advantage.

6. Overall Points About Tactics:

a. Reconnaissance Actions: Testing the opponent's reactions with beats and engagements helps in deciding the appropriate tactics. Observing opponents while not fencing them provides insights into their favorite moves and habits.

Main Points: Effective reconnaissance involves testing and observing the opponent to identify their tendencies and weaknesses. This information is crucial for developing a successful tactical approach.

b. Adaptability: Fencers should vary their tactical game to prevent opponents from predicting their actions. Each encounter is unique, requiring a tailored approach to outsmart the opponent.

Main Points: Adapting tactics based on the opponent and situation is essential for success. Avoiding predictable patterns and being flexible in your approach can turn the tide in your favor.

III. Common Visualization Methods in Sports

A. Motion Charts for Spatio-Temporal Data

To analyze and visualize the spatio-temporal movements of players, motion charts provide a dynamic and interactive solution [9]. This method involves using motion charts, which are dynamic bubble charts that map variables to time, 2D coordinates, size, and colors, facilitating the exploration of multidimensional and temporal data. These charts allow researchers to efficiently visualize both individual player movements and synchronized team movements. Popularized by Hans Rosling in his TED talks, the motion chart function within the googleVis package in R (gvisMotion Chart) enables users to visualize data stored in R data frames directly in a web browser, making it a powerful tool for preliminary analysis and result interpretation in sports research.

B. Gap Charts for Visualizing Rankings

To visualize the evolution of rankings over time, particularly in sports, Gap Charts [10] offer an innovative solution. Traditional ranking tables and line charts have limitations in displaying the magnitude of score differences and the temporal evolution of ranks. Gap Charts address these issues by using the y-axis to encode both ranks (top to bottom) and scores (bottom to top), with the gaps between lines representing score magnitudes. This method ensures that the chart remains overlap-free and clearly shows tied scores as adjacent entries. Gap Charts provide a comprehensive view of both ranking positions and score differences over time, making them a powerful tool for predicting future rankings and outcomes in sports championships.

C. Visual Analytics for Movement Analysis

The evolution of modern motion tracking technologies has greatly enhanced the practicality of movement analysis in professional sports like soccer. Visual Analytics (VA) [11] techniques empower users from media, sports analysis, coaching, and management sectors to derive valuable insights from complex tracking data. However, visualizing raw tracking data can often lead to severe overplotting and clutter. To mitigate this, an innovative VA approach integrates trajectory simplification and aggregation techniques within a generalization hierarchy. This method enables analysts to interactively explore different Levels of Abstraction (LoA) to determine the most suitable for their specific analysis task. Mirroring the tactical board sketches utilized by soccer experts, this approach facilitates smooth transitions between techniques and aids in forming a mental model of the underlying computations. Enhanced by interactive visualizations and a recommender system that predicts the desired LoA based on user feedback, this technique's usability has been proven through both qualitative and quantitative studies in soccer movement analysis. These studies help comprehend and evaluate visualizations effectively in real-time.

D. Multimedia Integration for Basketball Analysis

Basketball is a dynamic sport requiring rapid transitions between offense and defense. Traditional game narrations, reliant on domain experts, are time-consuming and lack timeliness. To address this, integrating multimedia data provides a comprehensive visualization of an entire NBA season [12], capturing multiple levels of detail: season, game, and session. At the season level, win-loss statistics and other metrics are visualized to compare team strengths and weaknesses. The game level visualizes the game's progression as an ordered sequence of sessions segmented by player substitutions. At the session level, actions are represented as glyphs, revealing key players and their contributions. Combining play-by-play data, video data, and action areas facilitates a multi-faceted session visualization. The GameFlow system leverages these visual designs to efficiently narrate NBA games, detailing actions, players, and sessions. This allows users to identify game intensity changes and explore factors contributing to the final score, providing a rich, contextually informed, and timely analysis of basketball games.

E. TenniVis for Tennis Match Analysis

Visualization plays a crucial role in match analysis across various sports. TenniVis [13] is a novel system designed to facilitate tennis match analysis through easy data collection, intuitive visualizations, hypothesis generation, and result sharing. It uses easily collectible data from a single video camera and basic match information recorded by a spectator. The system features two intuitive visualizations: the Pie Meter view, which gives a high-level match overview, and the Fish Grid view, which details point outcomes and game progression. TenniVis allows users to generate and evaluate hypotheses using filters and visual snapshots, and facilitates result sharing through annotated video clips compiled into an HTML report. Developed with input from non-professional tennis players and coaches, TenniVis has proven useful and feasible in enhancing tennis match analysis.

F. Taxonomy and Methods for Sports Data Visualization

Visualizing data in competitive sports is crucial for gaining insights into athletes' movements and actions. By dividing sports data into spatial-temporal details and numerical data, the focus is on three primary objectives: illustrating key features, contrasting these features, and forecasting them. The visualization techniques can be sorted into five main types: displaying high-dimensional data, time-based data visualization, graphical (network) depiction, symbol (glyph) representation, and other assorted methods [14]. This framework merges expertise from various fields such as data analysis, mining, computer graphics, and user interaction design, with a particular emphasis on visualizing time-series

data through innovative methods like spiral diagrams, date-based layouts, thematic river maps, and parallel coordinates. This structured approach assists in selecting the right strategies for various tasks and types of data, providing guidance and suggestions for advancing studies in the realm of human motion and conduct in sports.

G. SoccerStories for Soccer Match Analysis

Soccer matches are composed of multiple phases, such as midfield play, crosses, and goal attempts, which traditional quantitative analyses often fail to fully capture. Soccer experts, who rely heavily on their observations, need a comprehensive visual summary of the game to enhance their analysis and communication. SoccerStories [15] is a visualization interface designed to meet this need. It provides an overview detail interface that allows analysts to explore game phases in depth, while also aggregating these phases into a series of connected visualizations tailored to specific actions like passes or goal attempts. This system supports the current practices of soccer analysts, enriching their ability to analyze and communicate insights effectively. By focusing on the context, player positions, and phases of play, SoccerStories enables analysts to quickly identify key moments that explain game outcomes, such as red cards or goals, and highlight team tactics. This approach not only improves the efficiency of game analysis under tight deadlines but also enhances the overall understanding and storytelling of soccer matches.

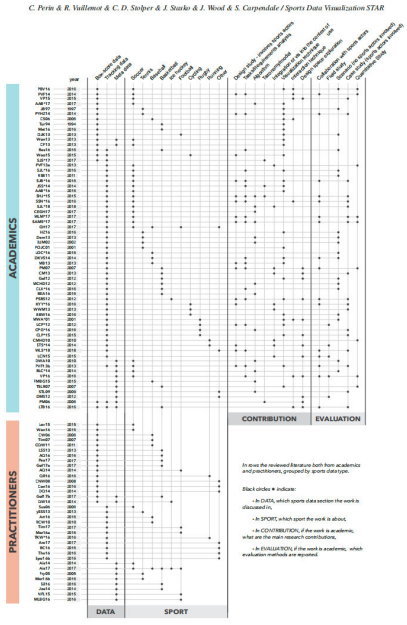

Fig. 2. Motion chart for spatio-temporal data [16].

IV. Fencing Data Visualization Methods

A. FencingVis for Visualization of Fencing Tactics

Fencing relies heavily on tactics, making traditional statistical analysis insufficient for uncovering hidden patterns. Many existing sports data visualization methods [17], such as those used for soccer and basketball, are not suitable for fencing due to the unique characteristics of its data. Similarly, visualization techniques for individual sports like table tennis and tennis do not apply well to fencing because of the hierarchical nature of their data, which differs significantly from fencing's time-series data. Fencing competition data consist of two related time-series datasets, which are complex and feature-rich, incorporating intricate tactical elements. These complexities make it challenging to analyze fencing data using conventional methods. To address this, FencingVis [18] has been developed. FencingVis, as shown in Fig. 3, is designed to analyze the action sequences in fencing bouts, extracting various tactical behaviors and constructing a graph model to represent these tactical combinations. The core feature of FencingVis is the tactical flow graph, which visualizes the constructed model and allows for interactive exploration. Additionally, FencingVis includes several coordinated views that display the competition data from multiple perspectives, seamlessly integrating with the tactical flow graph through a consistent visual style. This comprehensive approach enables a detailed analysis of fencing tactics, aiding both fencers and coaches in enhancing their strategies and understanding of the sport.

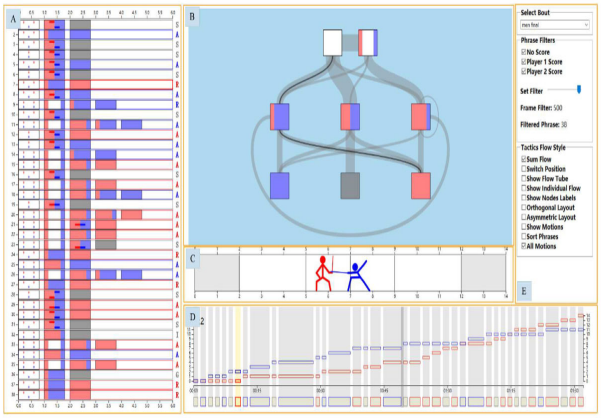

Fig. 3. Chart for visualizing rankings [19].

B. Analysis of the Fencing Lunge Based on Visual and Tactile Stimuli

The fencing lunge, a fundamental move in the sport, follows a traditional sequence involving starting from the en grade position, moving the front leg forward, extending the back leg, and finally stepping forward with the front leg. A study [19] analyzed the dynamic structure of the fencing lunge by examining muscle activation in response to visual and tactile stimuli. Six right-handed fencers performed six lunges each: three in response to a trainer's forward step (visual stimulus) and three in response to losing blade contact (tactile stimulus). Using a 16-channel Noraxon EMG system synchronized with a camcorder, the study recorded bioelectric muscle activity. Results showed that during a lunge responding to a visual stimulus, the triceps brachii of the armed limb was activated first, followed by the lateral head of the gastrocnemius muscle. In contrast, during a lunge responding to a tactile stimulus, the gastrocnemius muscles of the back leg were activated simultaneously first. Mean muscle tension was higher during lunges responding to losing blade contact. The study concluded that visual stimuli primarily activate the triceps brachii first, aligning with the traditional lunge sequence, while tactile stimuli alter this sequence by activating the gastrocnemius muscles first. Additionally, visual stimuli resulted in greater bioelectrical muscle activity, suggesting that waiting for and observing visual stimuli reduces muscle tension.

C. Advanced Training Devices for Technical and Tactical Improvement

The intensification of competitive activity in fencing and the trend of increasing sporting achievements have necessitated the development of technical devices to enhance the training of highly skilled fencers. Recent innovations, such as the "Tyshler's Simulator (TTD)" and the "Favero Fencing Target," focus on improving motor actions and solving situational tasks. However, these devices often overlook the importance of enhancing the specialized feel of the weapon by changing the blade's center of mass and fail to consider the need for processing more operational information to respond effectively to opponents' actions. They also do not account for variability in opponents' anthropometric characteristics. To address these gaps, new devices and simulators, including the "TTT" simulator, have been developed [20]. The "TTT" simulator enhances fencers' technical and tactical skills by improving tactical thinking and specific knowledge. It significantly improves the quantitative and qualitative aspects of training and reduces the time needed to process operational information, crucial for responding to opponents. This comprehensive improvement in technical, tactical, and theoretical training leads to better performance and higher achievements in competitions. The simulator can be used as a standalone training component or as part of a long-term training program across various types of weapons.

D. FenceNet: Automated Classification of Footwork Techniques

Fencing teams frequently rely on analytical tools to boost performance and optimize training strategies. The initial step involves comprehending the physical, tactical, and technical requirements of fencing to establish performance benchmarks across various skill levels. These benchmarks are crucial for pinpointing gaps, enhancing the accuracy of athlete evaluations, and assisting in athlete selection, skill development, and targeted training interventions. Nonetheless, a significant obstacle is the absence of a consistent method together high-quality, high-resolution, objective data, which is essential for setting these benchmarks. Presently, data analysis in fencing primarily relies on manual efforts by coaches and analysts. The traditional method of manually analyzing fencing movements is fraught with inefficiencies and inaccuracies due to the sport's complex, ever-changing, and nuanced physical actions. To tackle this problem, a new system called FenceNet [21] has been introduced. This innovative framework automates the identification of detailed footwork maneuvers in fencing. It processes 2D posture data and leverages a recognition method based on the skeleton model. This method is enhanced with temporal convolutional networks to ensure that the temporal dynamics of the movements are captured effectively. By implementing this automated system, the precision and efficiency of analyzing fencing movements are significantly improved, which in turn enriches the processes of training and performance assessment.

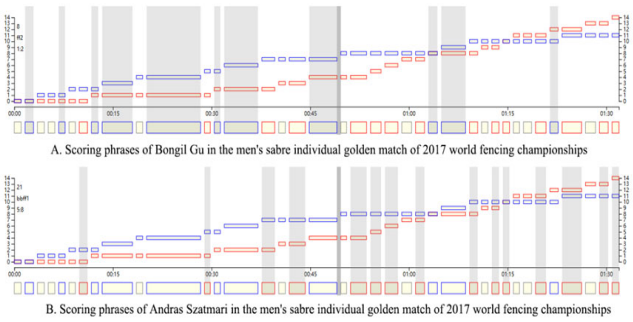

Fig. 4. Bout view of men's sabre individual golden match of 2017 world fencing championship with highlighted scoring phrase of each fencers [17].

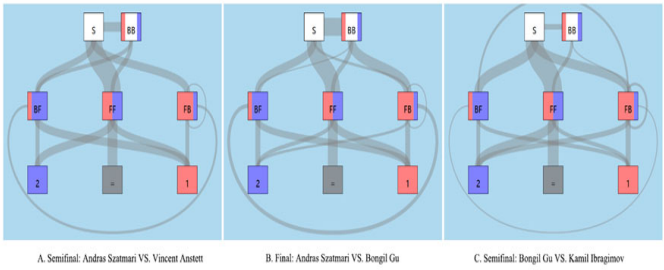

Fig. 5. Comparison of tactical flow graphs in the semi-finals and final of fencing world championships in 2017 [17].

V. Discussion

A. Scarcity of Effective Technical and Tactical Visualization Methods for Fencing Data

The visualization methods specifically tailored for fencing data are notably scarce, particularly those that address both technical and tactical aspects. Fencing is more abstract and harder to analyze than many other sports. For example, in table tennis, matches are divided into clear segments like games, rounds, and strokes, making it easier to categorize and visualize different techniques. In contrast, fencing bouts are composed of phases that are not easily segmented or described. Additionally, fencing relies heavily on tactics and strategic decisions based on the opponent's actions, which adds another layer of complexity. Many existing sports visualization methods are designed for team sports like soccer and basketball, where data characteristics are fundamentally different from those in fencing. Even individual sports like table tennis and tennis generate data with a hierarchical structure through alternating actions, which is not present in fencing.

The data from fencing competitions consist of two related time-series datasets, which are complex due to the embedded tactical features. Methods designed for other sports, such as bicycle racing, might seem applicable but fall short because fencing's timing sequences and tactical nuances are more intricate. Current analytical methods for fencing data primarily focus on technical aspects, often examining athletes from a biomechanical perspective. This includes comparing skilled fencers with beginners to identify key factors for training, but these methods rarely consider the tactical dimension of the sport. Statistical analysis of fencing data has been conducted, summarizing bouts into known patterns, but these models are limited and often require basic data recording, such as tracking feet and blade movements. While this basic level of data recording reduces costs and prevents information loss, it also necessitates further data

abstraction in the analysis phase. The lack of sophisticated, tailored visualization methods for fencing highlights a significant gap, emphasizing the need for more advanced tools that can capture and analyze the unique complexities of the sport, integrating both technical precision and strategic depth.

B. Leveraging Visualization Methods from Other Sports for Fencing

The scarcity of effective visualization methods specifically tailored for fencing data highlights an opportunity to borrow and adapt techniques from other sports. To address the challenges in fencing data analysis, we can explore the visualization methods used in other competitive sports, which generally fall into two main categories: spatio-temporal information and statistical information [16].

Spatio-temporal information refers to the spatial and temporal coordinates of players and objects during a game. This includes trajectory data, possession times, distances traveled, and more. In sports like soccer and basketball, spatio-temporal data is captured through various sensors, allowing analysts to study the dynamic behavior of players, analyze tactical decisions, and understand interactions among team members. This data helps predict future behaviors and make strategic decisions. For instance, visualizations of player movements and ball trajectories can reveal patterns and strategies that are crucial for game planning and analysis. In contrast, statistical information focuses on player performance metrics such as scores, shooting times, and personal statistics. This type of data is often easier to collect and can provide a comprehensive overview of a team's performance or a detailed analysis of specific events. In sports like tennis or table tennis, this information is used to compare player performances, analyze key events, and understand team tactics. These statistics can be visualized through charts and graphs, making it easier to identify trends and areas for improvement.

To make spatio-temporal data more intuitive, trajectory information can be presented using advanced visualization software. For example, player positions, possession data, and tactical movements can be mapped out to provide clear insights into game strategies. This method of visualization helps analysts and coaches understand the spatial dynamics of the game and make informed decisions based on the visual data. Time-series visualization is another powerful technique that can be adapted for fencing. This approach combines spatio-temporal data with geographic mapping to display information patterns over time. Techniques such as line charts, histograms, and flow maps can be used to visualize player movements and actions, showing how they evolve during a match. This can help identify trends and key moments that impact the outcome of the game. Network visualization, although less commonly used in sports due to its complexity, can also provide valuable insights. It represents data with nodes and links, highlighting relationships and influence patterns among players. For example, in fencing, this could be used to visualize the interactions between fencers during a bout, showing how different tactics and movements influence each other. Network visualization can dynamically update to reflect time-varying data, providing a real-time view of the competitive dynamics.

By adopting and adapting these visualization methods from other sports, we can develop more effective tools for analyzing fencing data. This approach will help bridge the gap in current methodologies, enabling deeper insights into both the technical and tactical aspects of fencing. Ultimately, this can enhance performance analysis, strategic planning, and the overall understanding of the sport, benefiting athletes, coaches, and analysts alike.

C. The Promising Potential of Deep Learning in Fencing Visualization

Recent advancements in deep learning have shown tremendous potential in revolutionizing the analysis and visualization of fencing techniques and tactics. Some pioneering studies have started using deep neural networks to analyze various aspects of fencers' movements, such as posture, actions, and footwork. These studies aim to capture and understand the intricate details of a fencer's performance. For example, researchers are investigating the trajectory of the sword, including the precise path of the sword tip [22, 23], which is crucial for understanding the accuracy and effectiveness of attacks and defenses. Other studies focus on predicting the timing of attacks, helping to identify the critical moments when a fencer is likely to strike. The dynamic and unpredictable nature of fencing makes it a particularly challenging sport to analyze using traditional methods. Fencing involves rapid, complex movements that require split-second decisions, making manual analysis inefficient and often inaccurate. This is where deep learning and Artificial Intelligence (AI) come into play. These technologies can process vast amounts of data quickly and accurately, extracting patterns and insights that would be impossible for humans to discern unaided [24].

Deep learning algorithms, particularly Convolutional Neural Networks (CNNs), excel in recognizing patterns and making sense of complex visual data. In fencing, this means they can analyze video footage to identify and classify different movements and techniques with high precision. This capability is especially valuable in a sport like fencing, where the subtleties of technique and strategy are paramount. By automatically classifying and analyzing these movements, AI can provide coaches and athletes with detailed feedback on performance, helping them to refine their techniques and develop more effective strategies.

Furthermore, AI can go beyond simple analysis to predict future actions based on past behavior. For instance, by analyzing the patterns in a fencer's movements, AI can predict when and how they are likely to attack. This predictive capability can be invaluable in developing counter-strategies and training fencers to anticipate their opponents' moves. Wearable technology can also play a role, providing real-time data on a fencer's physical condition, such as muscle strain and fatigue, helping to prevent injuries and optimize training regimens.

The integration of deep learning in fencing analysis is still in its early stages, but the potential benefits are clear. AI can provide a level of detail and accuracy in performance analysis that is unmatched by traditional methods. It can help uncover new insights into the technical and tactical aspects of fencing, leading to improved training methods and better performance

outcomes. As these technologies continue to develop, they are likely to become an indispensable tool for fencers and coaches, transforming the way the sport is analyzed and understood. Thus, the application of deep learning and AI in fencing visualization holds great promise. These technologies can handle the sport's dynamic and unpredictable nature, providing detailed and accurate analysis of techniques and tactics. As research in this area progresses, deep learning is set to become a powerful tool in advancing the understanding and performance of fencing, offering unprecedented insights and improvements in training and competition [1].

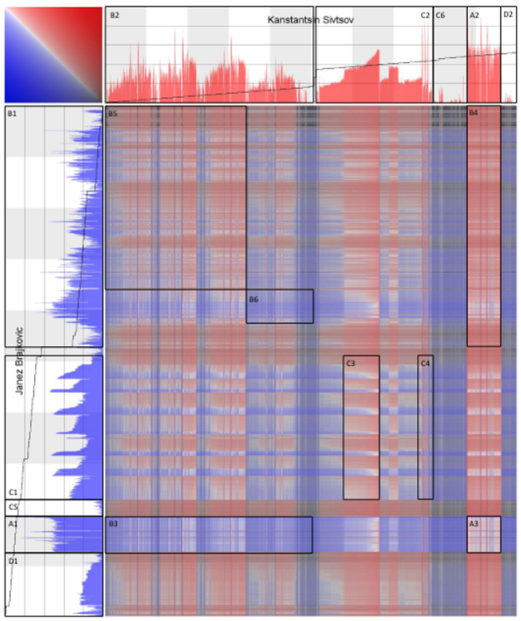

Fig. 6. Comparing the performance (power)of Kanstantsin Sivtsov (red) against Janez Brajkovic (blue) in the prologue of Tour de France 2012 including their preparation period for the race [24].

VI. Conclusion

The analysis and visualization of technical and tactical aspects in fencing require specialized methodologies due to the sport's unique characteristics and complex data structures. Traditional visualization tools, while effective in other sports, fall short in capturing the nuanced and dynamic nature of fencing. This review underscores the lack of effective, specialized visualization methods for fencing and highlights the need for innovative approaches. By adapting visualization techniques from other sports and integrating advanced technologies like deep learning, we can create more sophisticated tools for analyzing fencing data. Deep learning shows great promise in providing detailed and accurate insights into fencers' movements and strategies, thereby enhancing training and performance evaluation. As these technologies continue to evolve, they have the potential to revolutionize fencing analysis, offering significant benefits to athletes, coaches, and analysts. This paper calls for ongoing research and development of advanced, customized visualization solutions that meet the specific demands of fencing, ultimately contributing to the sport's growth and competitive success.

Conflict of Interest

The author has claimed that no conflict of interest exists.

References

[1] A. Sowerby, *Fencing: Skills. Tactics. Training*. Crowood, 2014.
[2] G. Shaw, "Fencing instruction for children," *Strategies*, vol. 22, no. 2, pp. 13–17, 2008.
[3] D. Werner, *Fencer's Start-Up: A Beginner's Guide to Fencing*, Tracks Publishing, 2010.
[4] V. Bhatt, U. Aggarwal, and C. N. S. V. Kumar, "Sports data visualization and betting," in *Proc. 2022 International Conference on Smart Generation Computing, Communication and Networking (SMART GENCON)*, IEEE, 2022, pp. 1–6.
[5] R. C. Basole and D. Saupe, "Sports data visualization [Guest editors' introduction]," *IEEE Computer Graphics and Applications*, vol. 36, no. 5, pp. 24–26, 2016.
[6] K. Zhu, A. Wong, and J. McPhee, "Fence net: Fine-grained footwork recognition in fencing," in *Proc. Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, June 2022.
[7] T. Christine, *How to Fence_ Your Step-by-Step Guide to Fencing*, How Expert, 2013.
[8] J. Routledge, *Foil Fencing: Skills, Strategies and Training Methods*, The Crowood Press, 2022.
[9] R. Metulini, "Spatio-temporal movements in team sports: a visualization approach using motion charts," *arXiv preprint arXiv:1611.09158*, 2016.
[10] C. Perin, J. Boy, and F. Vernier, "Using gap charts to visualize the temporal evolution of ranks and scores," *IEEE Computer Graphics and Applications*, vol. 36, no. 5, pp. 38–49, 2016.
[11] N. Andrienko and G. Andrienko, "Visual analytics of movement: An overview of methods, tools and procedures," *Information Visualization*, vol. 12, no. 1, pp. 3–24, 2013.
[12] W. Chen, T. Y. Lao, J. Xia, X. X. Huang, B. Zhu, and W. Q. Hu, "Game flow: Narrative visualization of NBA basketball games," in *Proc. IEEE Transactions on Multimedia*, vol. 18, no. 11, 2016, pp. 2247–2256. doi: 10.1109/TMM.2016.2614221.
[13] T. Polk, J. Yang, Y. Hu, and Y. Zhao, "Tennivis: Visualization for tennis match analysis," *IEEE Transactions on Visualization and Computer Graphics*, vol. 20, no. 12, pp. 2339–2348, 2014.
[14] M. Du and X. A. Yuan, "Survey of competitive sports data visualization and visual analysis," *Journal of Visualization*, no. 24, pp. 47–67, 2021.
[15] C. Perin, R. Vuillemot, and J. D. Fekete, "Soccer stories: A kick-off for visual soccer analysis," *IEEE Transactions on Visualization and Computer Graphics*, vol. 19, no. 12, pp. 2506–2515, 2013.
[16] C. Perin, R. Vuillemot, C. D. Stolper, J. T. Stasko, J. Wood, and S. Carpendale, "State of the art of sports data visualization," *Computer Graphics Forum*, vol. 37, no. 3, pp. 663–686, June 2018.
[17] M. Zhang, L. Chen, X. Yuan, R. Huang, S. Liu, and J. Yong, "Visualization of technical and tactical characteristics in fencing," *Journal of Visualization*, vol. 22, no. 1, pp. 109–124, Oct. 2018.
[18] Z. Borysiuk, N. Markowska, and M. Niedzielski, "Analysis of the fencing lunge based on the response to a visual stimulus and a tactile stimulus," *Journal of Combat Sports & Martial Arts*, vol. 5, no. 2, 2014. 10.5604/20815735.1142448
[19] B. Yuriy, P. Maryan, Z. Olha, S. Serhiy, and S. Zoryana, "Technical devices of improvement the technical, tactical and theoretical training of fencers," *Journal of Physical Education and Sport,* vol. 14, no. 3, p. 337, 2014.
[20] K. Zhu, A. Wong, and J. McPhee, "Fence net: Fine-grained footwork recognition in fencing," in *Proc. the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, 2022, pp. 3589–3598.
[21] T. Sawahata, A. Moro, S. Pathak, and K. Umeda, "Instance segmentation-based markerless tracking of fencing sword tips," in *Proc. 2024 IEEE/SICE International Symposium on System Integration (SII)*, Ha Long, Vietnam, 2024, pp. 472–477. doi: 10.1109/SII58957.2024.10417603.
[22] M. Takahashi, S. Yokozawa, H. Mitsumine, T. Itsuki, M. Naoe, and S. Funaki, "Real-time visualization of sword trajectories in fencing matches," *Multimedia Tools and Applications*, no. 79, pp. 26411–26425, 2020.
[23] A. Liu, R. P. Mahapatra, and A. V. R. Mayuri, "Hybrid design for sports data visualization using AI and big data analytics," *Complex & Intelligent Systems*, vol. 9, no. 3, pp. 2969–2980, 2023.
[24] F. Beck, M. Burch, and D. Weiskopf, "A matrix-based visual comparison of time series sports data," *Vision Modeling and Visualization*, pp. 53–60, Oct. 201