PanoCoach: Enhancing Tactical Coaching and Communication in Soccer with Mixed-Reality Telepresence

Andrew Kang*
Harvard University
USA
Rice University
USA
ak108@rice.edu

Hanspeter Pfister
Harvard University
USA
pfister@seas.harvard.edu

Tica Lin
Harvard University
USA
mlin@g.harvard.edu

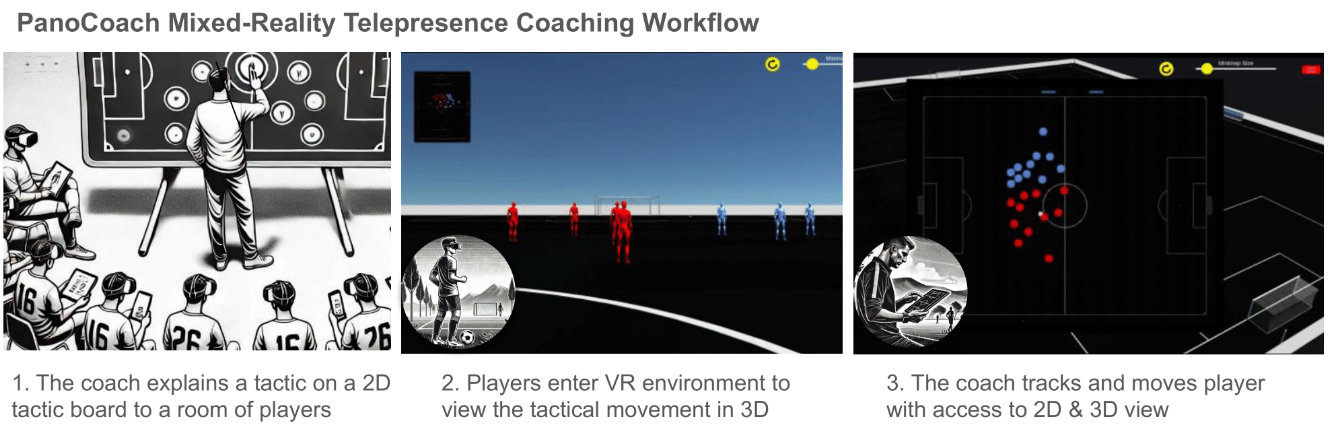

Figure 1: PanoCoach enhances tactical coaching by synchronizing a 2D tablet view with a simulated 3D environment. The proposed mixed-reality telepresence approach enables players to develop spatial understanding of complex team tactics from an immersive first-person perspective, while allowing coaches to maintain the ability to annotate and reposition players on the 2D board. This setup ensures that players receive immediate feedback from the coach while engaged in the 3D environment. Conceptual illustrations are generated by Dall-E. PanoCoach prototype views were implemented with Unity.

Abstract

Soccer, as a dynamic team sport, requires seamless coordination and integration of tactical strategies across all players. Adapting to new tactical systems is a critical but often challenging aspect of soccer at all professional levels. Even the best players can struggle with this process, primarily due to the complexities of conveying and internalizing intricate tactical patterns. Traditional communication methods like whiteboards, on-field instructions, and video analysis often present significant difficulties in perceiving spatial relationships, anticipating team movements, and facilitating live conversation during training sessions. These challenges can lead to inconsistent interpretations of the coach's tactics among players, regardless of their skill level.

To bridge the gap between tactical communication and physical execution, we propose a mixed-reality telepresence solution, PanoCoach, designed to support multi-view tactical explanations during practice. Our concept involves a multi-screen setup combining a tablet for coaches to annotate and demonstrate concepts in both 2D and 3D views, alongside VR to immerse athletes in a first-person perspective, allowing them to experience a sense of presence during coaching.

In our preliminary study, we prototyped the cross-device functionality to implement the key steps of our approach: Step 1, where the coach uses a tablet to provide clear and dynamic tactical instructions, Step 2, where players engage with these instructions through an immersive VR experience, and Step 3, where the coach tracks players' movements and provides real time feedback. User evaluation with coaches at City Football Group, Harvard Soccer and Rice Soccer suggests this mixed-reality telepresence approach holds promising potential for improving tactical understanding and communication.

Based on these findings, we outline future directions and discuss the research needed to expand this approach beyond controlled indoor environments, such as locker rooms, leveraging telepresence to enhance tactical comprehension and simulated training.

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• **Human-centered computing** → *Mixed / augmented reality.*

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1 VR in Sports Training

The potential of VR to assess and train team sports performance has been explored extensively. Faure et al. [3] highlight VR's capability to simulate realistic game environments for training in team ball sports. Studies have demonstrated that visual stimuli training programs can significantly enhance cognitive function, reaction time, and spatial awareness in soccer players [10]. Fortes et al. [4] argue that VR offers more effective perceptual-cognitive skill development compared to traditional video-stimulation training, making it particularly beneficial for young athletes. More generally, VR has proven advantageous for enhancing anticipatory performance and perception-action coupling in sports like baseball and rugby [2, 9]. Van Maarseveen et al. [12] and Theofilou et al. [10] emphasize the importance of perceptual-cognitive skills in situ, where players must make decisions based on real-time affordances within dynamic environments.

VR Applications are also being extended to sports other than soccer, such as basketball[11], baseball[8] and badminton [7], showing the positive impact of VR-based training on tactical awareness, reaction time, and even batting performance through AI-driven feedback systems. In dance and motion-based activities, VR systems like WAVE[6] demonstrate how anticipatory movement visualization can be adapted for training, an approach that has potential crossover benefits in high-performance sports such as soccer. Furthermore, animated VR and 360 degree VR are becoming prominent tools for the evaluation and training of decision making in team sports, offering unique insights into spatial relationships and tactical understanding [5].

While previous research has focused on enhancing motion learning and decision-making with VR, few studies have addressed facilitating real-time coaching and communication, particularly for complex team tactics that require coordinated teamwork. Our work serves as a preliminary exploration into the potential of mixed-reality telepresence in tactical coaching to bridge this gap.

2 PanoCoach Design

2.1 Interviews with Soccer Teams

Although prior findings have established the foundation for integrating panoramic views or VR into coaching, the challenge of helping players internalize complex tactical ideas persists. To understand the challenges further, we conducted interviews with key personnel from professional clubs. These 45-60 minute interviews were conducted with head coaches, assistant coaches, and performance analysts from City Football Group, Harvard Soccer, and Rice Soccer. The interviews focused on understanding their current challenges in tactical communication, the effectiveness of existing tools, and their expectations from a mixed-reality coaching solution. Three key challenges were identified:

- Challenge 1: Difficulty in conveying spatial relationships and team movements from multiple perspectives.
- Challenge 2: Lack of real-time feedback and adjustments during tactical drills, due to voices being unheard on the training ground or players not actually moving while relying on whiteboard visuals.
- Challenge 3: Need for collaborative interaction among players and coaches in a shared environment, due to players remaining static during whiteboard sessions and coaches struggling to monitor every subtle movement on the field.

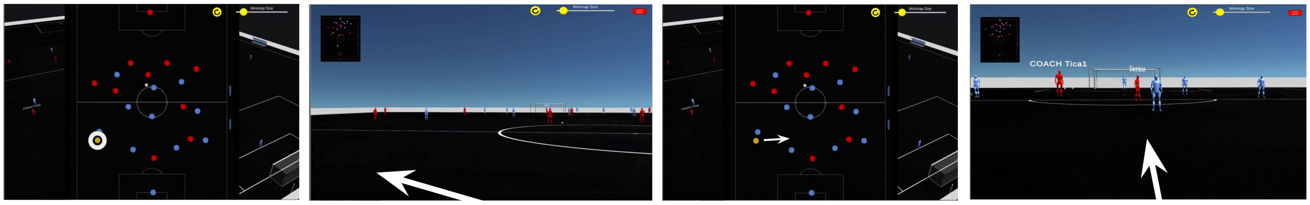
2.2 Prototype Design

To address these challenges, we designed a VR coaching tool that incorporates the features bulleted below. For development, we used a Unity environment (2022.3.31f1) with WebXR by De-Panther, WebGL2, and Windows builds for maximum compatibility with most personal devices. The server infrastructure was supported by Photon PUN2, a third-party networking solution. The VR device we used for prototyping is Oculus Quest 2.

- **Multi-perspective viewing across devices**: The tool supports cross-device compatibility (VR, computer, smartphone/ tablet), enabling remote collaboration between players and coaches. By combining first-person view (FPV), a 2D minimap, and broadcast-style video, it enhances spatial understanding and helps players better visualize tactical movements, addressing the challenge of conveying complex spatial relationships (Challenge 1).
- **Real-time annotation capabilities**: Coaches can provide immediate feedback through both voice and visual cues during live sessions, ensuring players actively apply corrections. This feature addresses the challenge of making timely adjustments and overcoming communication barriers during training (Challenge 2).
- **Multiplayer support**: The tool allows coaches and players to interact in real time, with coaches guiding players via a 2D interface while multiple players engage in a 3D environment. This collaborative setup addresses the challenge of synchronizing team coordination and monitoring player movements more effectively than traditional methods (Challenge 3).

3 User Evaluation

The user evaluation aimed to gather feedback on the initial prototype of PanoCoach and validate its potential to enhance tactical understanding and communication. We conducted feedback sessions with the same key stakeholders from earlier interviewes to assess effectiveness of PanoCoach in meeting the goals of these soccer teams. During the initial interviews (as shown in Section 3), these organizations expressed the following needs:



1. The coach creates a counter-attack situation on the 2D interface. The focus is on the red right-winger (RW)'s offensive positioning. The coach instructs RW to stay more open to potential passes.
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2. RW views own assigned position in a 3D view and can move freely in VR. However, RW sees own role as primarily creating goal-scoring opportunities, thus staying wider than the coach wants.

3. The coach notices that the right winger hasn't moved into the correct position to provide width on the flank. The coach gives verbal instructions to the winger and, when the player still doesn't adjust, the coach uses the interface to drag the winger into the correct spot on the field, ensuring the team maintains its attacking shape.

4. Meanwhile, the midfielder observes the movement of the RW and adjusts own positioning to create more space.

Figure 2: Example PanoCoach use case. Different users are presented with tailored visuals and actions based on their roles.

- **City Football Group**: Prioritized the need for a user-friendly interface for coaches within sandbox environments. Envisioned using this tool for self-assessment of retention of tactics in small group training.
- **Harvard Soccer**: Requested features such as adding a ball and drawing 3D arrows for player movement, in addition to incorporating short pre-recorded clips for quick tactical meetings.
- **Rice Soccer**: Highlighted the importance of repetitive tactical practice without physical load, specifically for set plays and strategic shifts during matches. They emphasized separating this tool from physical training sessions, using it primarily for mental conditioning.

During the evaluation, we presented PanoCoach functionality with example tactical coaching scenarios similar to those in Fig. 2 and encouraged coaches to interact with the tool while verbalizing their thoughts on its potential applications. The City Football Group saw value in the tool for remote learning, especially for loaned-out players (at different clubs) or those recovering from injury. Harvard appreciated the interactive nature of the tool, noting that it could help maintain player focus during meetings by allowing active engagement with the content rather than passively observation of videos. Rice highlighted the tool's effectiveness in reinforcing in-game tactical shifts without adding unnecessary physical strain on the players.

3.1 Insights

We summarized the potential benefits of applying PanoCoach to facilitate soccer tactic coaching from user feedback.

Rehearsal of Tactical Training Scenarios: The tool enables repeated practice of specific team movements without physical strain, something difficult to achieve in real-world training due to time constraints and player fatigue. This allows for focused tactical repetition, leading to better mastery of complex formations and in-game responses under pressure.

Enhanced Memorability: The tool strengthens the memory retention of players by immersing them repeatedly in first-person scenarios, creating vivid mental imprints. This direct engagement is more effective than the abstract imagery of tactic boards or passive video analysis.

Attention Guidance: The interactive platform keeps players actively engaged by letting them interact with the coach's visuals in real-time. Even in a remote environment, coaches can confirm that players understand the tactics conveyed. This mode is more effective than traditional lecture-style explanations or videos to watch at home.

3.2 Limitation and Future Iteration

Despite the positive feedback from the users, we found several challenges in deploying PanoCoach for actual use in teams and leagues. First, teams and coaches have varying interests in incorporating an experimental mode of technology into the training workflow of athletes. As seen in our user evaluation, each team's method of communication tactics varies. For coaches who prefer more traditional or abstract communication with whiteboards, a multi-perspective visualization may offer limited benefits. Second, the quality of our visualization is constrained by the hardware requirements of soccer organizations. More realistic graphics and animation could create stronger imagery for players to recall during specific game scenarios. Third, the user interface for coaches could be improved for greater efficiency. Under the current implementation, the avatars must be moved by the coach or player. Implementing a rule-based or AI-generated algorithm to automatically generate trajectories could significantly enhance usability and effectiveness for coaches.

Future iterations of a virtual coaching tool like PanoCoach could focus on refining key features based on feedback from professionals. In the short term, effective improvements might include automated tracking of game data from training clips, expandeded recording options, and compatibility with video analysis platforms commonly used at clubs. Moreover, the benefits of this tool could easily be expanded to other sports where synchronized movements are crucial, such as basketball or hockey. Our ongoing collaboration with leading sports organizations will also drive this development.

4 Discussions & Future Directions

Our PanoCoach prototype and user evaluation suggested the potential usefulness of mixed reality telepresence in real soccer practices. To realize the entire workflow illustrated in Fig. 1, there remain several open questions to design and evaluate a multi-person mixed-reality telepresence coaching workflow. Based on insights from this initial study, we point out three challenges and future research directions:

4.1 Translating movement across views

The primary objective of integrating mixed-reality telepresence into sports training is to enhance the understanding of team movements, both before and during practice, through effective communication and scenario simulation. While PanoCoach allows for flexible transition between 2D and 3D views, these shifts in perspectives can sometimes introduce confusion due to the distinct interaction paradigms. Actions that feel intuitive on a 2D touchscreen, such as moving a player from a top-down perspective, may not directly translate to the first-person perspective in an immersive environment.

One critical challenge is maintaining clarity when communicating across the 2D tactical board and the 3D environment. For example, when a coach adjusts a player's position on the 2D tactic board, this movement is immediately apparent. However, in the 3D view, it becomes essential to inform the repositioned player and ensure that other players can anticipate these movements to maintain a cohesive understanding of the movement sequences. In addition, the 3D environment enables flexible interactions for players and offers more realistic motion cues in the player avatars, such as the direction a player is facing or the player height and speed—details that might not be as apparent on a 2D board. It is crucial to design interactions and visualizations that effectively convey these nuances across 2D and 3D views to facilitate shared understanding between coaches and players.

To address these challenges, future research can explore the design space for visualizing movement across 2D and 3D co-presence environments. This could involve translating visual cues between 2D and 3D, such as using interpolated or delayed movements of coach-controlled avatars shown in immersive environment, and enhancing interactions between users across views. For example, dynamically displaying and updating a player's position and orientation on both the 2D board and in VR could ensure that coaches and players share a real-time understanding of movement across different perspectives.

4.2 Visualizing annotation across platforms

To facilitate players' understanding of tactics, coaches frequently make annotations on 2D tactical boards. Although visualizing 2D annotations to a 3D environment has been extensively studied before, such as placing co-located minimaps or embedding annotations in a 3D environment [1, 13], in physical sports training, augmenting such visualizations onto a 3D view requires additional considerations, particularly from the perspectives of user needs and visualization effectiveness.

First, given the aim of tactical training, it is crucial to determine how much information is useful and necessary to display in VR. Most athletes train to enhance mental and muscle memory, so annotations should not interfere with their physical activity, even during simulated rehearsals in an immersive environment. Second, from a design perspective, several limitations need to be addressed when dealing with dynamic spatial data. For example, annotations that are further away may not be easily visible in a standard 3D embedded visualization from a first-person perspective. Additionally, during physical activities, visualizations that need to be interpreted while in motion [14] should be carefully designed to avoid cognitive overload and ensure they are supportive rather than distracting.

Further research is required to explore how best to convert these annotations into 3D environments to realize the mixed-reality sports training, considering factors such as the optimal amount and type of information to display on each platform, the visibility and accessibility of annotations in a 3D space, and the impact of these visualizations on athletes' performance during physical activities.

4.3 Beyond tactical understanding

Based on user feedback, rehearsing tactics without engaging in group physical activities has emerged as a promising application of this mixed-reality telepresence training approach. This approach not only facilitates group training with fewer physical constraints but also allows injured players to participate in tactical sessions, maintaining their engagement and understanding of team strategies. As a result, this approach may offer significant potential for innovative training methods in team sports, overcoming both physical and temporal limitations.

However, a significant challenge lies in validating whether these rehearsed tactics are genuinely internalized and can be effectively translated into real-world performance. One critical issue is the difference between cognitive understanding and physical execution. While players may be able to visualize and mentally rehearse tactics and train their individual movement in a mixed-reality environment, this does not guarantee that they can execute these tactics effectively during actual gameplay with real players. Due to the limitation of visualizations of virtual avatars in AR/VR, the speed, pressure, and environmental factors of a live game may not be properly represented during these simulated training. Additionally, the lack of physical cues and kinesthetic feedback in a simulated environment can make it difficult for players to fully grasp the timing, spacing, and coordination required for successful tactic execution. For example, in a mixed-reality rehearsal, players might not experience the physical exertion or spatial awareness that comes with actual movement, potentially leading to a gap between their virtual preparation and on-field performance.

To elevate mixed-reality telepresence from tactical understanding to practical training, future research should focus on on integrating key physical data into virtual avatars and environments to more accurately simulate live gameplay. These improvements can help bridge the gap between virtual rehearsals and actual performance, making mixed-reality training more effective. Additionally, longitudinal studies should assess the long-term impact on in-game performance, guiding further directions of mixed-reality telepresence in sports.

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