Vector field theory in motion: Revealing latent potentials in football dynamics

Paula Rodríguez-Sánchez[1,2], José J. Ramasco[3], Javier M. Buldú[1,2], Johann H. Martínez[1,2]

[1]Complex Systems Group, Universidad Rey Juan Carlos, Móstoles, Madrid, Spain
[2]Grupo Interdisciplinar de Sistemas Complejos (GISC), Madrid, Spain
[3]Instituto de Física Interdisciplinar y Sistemas Complejos IFISC (CSIC-UIB), Campus UIB, 07122 Palma de Mallorca, Spain

Abstract

Recent advances in player and ball tracking technologies have significantly expanded the scientific capacity to study emergent patterns in collective sports [1]. In this study, we introduce a method to construct vector fields from high-resolution tracking data in soccer [2, 3]. We analyzed the players' speeds acquired during 100 matches of the 2019/2020 LaLiga season, unveiling the corresponding scalar potentials as characteristic fingerprints of team behavior. First, we reconstructed the flow velocity fields from player and ball position data sampled at 25 frames per second. The resulting fields satisfied Gauss's divergence theorem and exhibited irrotational properties, thereby allowing us to retrieve the underlying conservative scalar potentials of teams. This vector field formulation was applied to both ball trajectories and player movements, analyzed during offensive and defensive phases. Taking into account the irrotational nature of the fields, we reconstructed aggregate potential fields by combining data from all matches and teams, separately for each dynamic phase of the game. These aggregated potentials capture the common spatial patterns and directional flows underlying professional soccer, revealing source and sink regions that highlight asymmetries in team behavior and movement dynamics. After establishing this global reference framework, we computed the individual vector fields and corresponding scalar potentials for each team, enabling comparative analyses that reveal differences in strategic organization and collective performance. To quantify these differences, we compared the maximum and minimum values of the scalar potentials across teams. We observed that some teams exhibit higher absolute values of both positive and negative potentials, while others display lower potential gradients. These patterns reflect variations in the speed, intensity and coordination of play. To the best of our knowledge, this is the first field-theoretic approach in collective sports to offer a physical framework for understanding team organization and match dynamics, while also providing practical tools for applied contexts such as training design, tactical analysis, and performance evaluation.

References

[1] Buldú, J.M., Busquets, J., & Echegoyen, I. Defining a historic football team: Using Network Science to analyze Guardiola's F.C. Barcelona. *Sci Rep* **9**, 13602 (2019).

[2] Mazzoli, M., Molas, A., Bassolas, A., Lenormand, M., Colet, P., & Ramasco, J. J. Field theory for recurrent mobility. *Nat Commun* **10** (2019).

[3] Liu, E., Mazzoli, M., Yang, X.-Y., & Ramasco, J. J. A generalized vector-field framework for mobility. *Commun Phys* **7**, 190 (2024).