RoboCup Soccer Autonomy Uprising: How Crowds, Referees, and Humanoid Robots Are Redefining the Future of Human-Robot Interaction

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***Abstract*—This paper explores the dynamics of Human-Robot Interaction (HRI) in public spaces, focusing on how humanoid robots engage with human crowds in the competitive RoboCup Soccer environment. We examine the role of spectatorship, where emotional engagement arises through indirect observation of engineering-driven competition, drawing parallels between human soccer and robot sports. The potential for autonomous systems to elicit collective emotions and systematically study such experiences is investigated. Using the Autonomy Levels for Unmanned Systems (ALFUS) framework, we assess RoboCup soccer robots' autonomy in terms of mission complexity (MC), environmental complexity (EC), and external system independence (ESI). Additionally, the Autonomy and Technology Readiness Assessment (ATRA) method supports gradual capability enhancement, providing a roadmap to higher autonomy. Based on this established methodology, we introduce the *Robot-Crowd Interaction Framework* (R-CIF), a novel conceptual framework defining the roles of actors involved, to connect theoretical insights with real-world applications. This work highlights the significance of crowd affectivity in robotic sports to boost public engagement and proposes directions for future research on collective emotional dynamics in HRI.**

***Index Terms*—Human Robot Interaction, Crowd Interaction, Explainable Artificial Intelligence**

I. INTRODUCTION

Humanoid robots are increasingly significant in Human-Robot Interaction (HRI) [1]. A key challenge in advancing robot autonomy in real-world settings is mitigating risks to humans, the environment, or the robots during development. Identifying safe environments for testing these technologies before practical deployment is essential. RoboCup competitions [2] offer controlled, dynamic, and publicly engaging platforms for advancing robotic autonomy in domains such as robot sports, domestic service, logistics, manufacturing, education, and urban search and rescue. These events enable robots to tackle complex tasks while reducing real-world risks, fostering innovation in autonomous robotics beyond research communities. Such competitions push the boundaries of robotic capabilities and accelerate their real-world applications.

Fig. 1. Assessment of humanoid robot autonomy and crowd interaction in RoboCup Soccer (top), compared to human soccer (bottom). The RoboCup Soccer features a crowd, programmers (right), and referees in black-and-white.

The RoboCup Soccer Standard Platform League (Soccer SPL) offers a dynamic platform that combines real-time strategic tasks with team-oriented goals. The gamified setting — where robots must manoeuvre, strategise, and decide swiftly amidst the unpredictable dynamics of a soccer match — acts as both a development arena and a ground for advanced autonomy. The competitive aspect adds an extra layer of complexity, requiring humanoid robots to perform in a fast-paced setting while also collaborating with human referees,

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[§] Corresponding author: filippo.sanfilippo@uia.no interacting with the crowd, and engaging with human experts and supervisors. By replicating a real-world sport in a controlled format, the Soccer SPL provides a safe arena to advance autonomy without real-world risks.

This paper re-imagines HRI in the context of robot soccer, specifically provoking discussion on how humanoid robots interact with crowds during competitive events. We analyse the significance of spectatorship and how robots can evoke collective emotions, drawing comparisons between human sport fans and robot sport audiences, as shown in Fig. 1. By examining the effects of increasing autonomy, we aim to advance HRI research through a systematic study of interactions. Like human soccer, interaction dynamics shift significantly as robots gain autonomy. Initially, robots depend heavily on expert programmers, akin to novice players guided by a coach. With greater autonomy, they begin to mimic human teams, responding to crowd dynamics, adapting strategies in real time, and executing coordinated plays independently. Referees ensure fair play while supporting strategic complexity. Programmers transition to roles similar to coaches, focusing on overarching strategy and enabling robots to learn from successes and failures. This evolution enhances humanoid robot performance and reflects the social dynamics of human soccer, where teamwork, crowd influence, and coaching play critical roles. Understanding these parallels can inform how autonomous systems thrive in human-centered environments, driving innovations in robotics and explainable AI (XAI).

To follow a systematic methodology, the Autonomy Levels for Unmanned Systems (ALFUS) framework is utilised to evaluate the autonomy of RoboCup soccer robots, considering factors such as mission complexity (MC), environmental complexity (EC), and external system dependence (ESI). Furthermore, the Autonomy and Technology Readiness Assessment (ATRA) methodology is adopted as a guiding model to incrementally develop these robots' abilities, ensuring a structured pathway towards achieving higher autonomy while addressing both technological and adaptive challenges. This work contributes to the field by introducing a conceptual framework for crowd-robot interaction, termed the *Robot-Crowd Interaction Framework* (R-CIF). This framework defines and contextualises the roles of key actors, leveraging these established autonomy frameworks to provide a structured approach for understanding and improving these interactions. This position-oriented paper aims to provide a step-wise approach for advancing the capabilities of RoboCup soccer robots in guidance, navigation, and control (GNC), targeting various levels of autonomy. By doing so, the paper not only contributes to the progression of robotic sports but expands the bounds of HRI by seeking to enhance public engagement with autonomous systems.

The paper is structured as follows. A review of the related research works is given in Section II. Section III overviews the Soccer SPL, emphasising its role in advancing robotic autonomy and HRI. In Section IV, we adopt the ALFUS framework and demonstrate its application within the Soccer SPL context. In Section V, an exploration of the ATRA framework and HRI in RoboCup Soccer is outlined. Based on this methodology, the *Robot-Crowd Interaction Framework* (R-CIF) is introduced. Section VI presents a case study that explores both the applicability of the proposed framework and the potential methods for communicating inner-system autonomy processes to a crowd. Conclusions and future works are discussed in Section VII.

II. RELATED WORKS

Research on affective spectatorship in robot sports like Soccer SPL is still nascent. Few studies, if any, delve into understanding the emotional dynamics of spectators watching robot sports. Antonioni *et al.* [3] investigate how audience noise informs autonomous decision-making, using crowd audio-scapes as reinforcement learning data to predict decision outcomes. Willis [4] takes another perspective, investigating how artificial emotions can add competitive advantage to RoboCup teams. Suzuki *et al.* [5] address spectator disappointment when robot soccer fails to match the pace and immediacy of human games, impacting perceptions of both the robots and AI capabilities. To address this, Suzuki and colleagues develop a visualisation system to help audiences predict on-field situations which aid in expectation adjustment, mitigating negative effects of mismatch between actual performance and predicted performance.

More often, scholars focus on how robotics can support and enhance the spectator experience. This includes enhancing the experience of watching typical 'human' sports, such as motor sports, ball and field sports [6], [7], spectator perceptions of robot umpires [8], [9], and the public perception of AI-generated news articles for robot sports [10]. However, the complexity of both human cognitive-affective processes in HRI, and the cognition (comprehension) of what types of processes are at play when considering the sport of 'autonomous robot player' programming, warrants deeper research.

We propose that the 'game' and 'sport' of robot soccer should be re-imagined within the context of HRI. Spectators should be empowered to comprehend what they are witnessing - not as a demonstration of physical power and control, but rather, autonomous engineering prowess. It should be the *systems* that are followed, rather than purely the humanoid copies of soccer gameplay. Building on Stone's work [11], the programming and system development should be integral to the sport itself. The challenge lies in communicating these inner-system autonomy processes clearly and emotionally to non-expert audiences. Our aim is to foster an atmosphere where spectators, both novice and expert, focus on the systems' inner workings rather than comparing the sport to human soccer.

Motivating Crowd-based HRI

The exploration of these questions is illustrated in a study of social robotics from an unusual perspective - interactive artworks - such as the "Fish-Bird: Circle B – Movement C" [12] interactive exhibition with two wheelchair robots. The robots, Fish and Bird, move in a pseudo-dance, creating an autokinetic artwork that engages not just individuals, but also creates a collective experience [13] for the watching crowd. Moving within a defined space, the robots print poetic verses, narrating their love and heartbreak over "technical difficulties" preventing their union. This narrative particularly captivates children, who often anthropomorphise the robots, interacting with them as if alive. One girl, deeply moved by the story, cried upon realising Fish and Bird could never be together, a sentiment echoed empathetically by others in the crowd. HRI in this exhibition extends beyond individuals to include collective crowd engagement. While the girl's emotional response is striking, the crowd's shared reaction highlights the complexity of HRI in public spaces. Fish-Bird and similar exhibitions [14] demonstrate how crowds shift from viewing robots as objects to connecting emotionally with anthropomorphised characters performing a tragedy, much like audiences in a stage play. This work aims to steer HRI research toward understanding how autonomous robots engage with crowds and how such interactions can be systematically studied and evaluated.

III. ROBOCUP SOCCER STANDARD PLATFORM LEAGUE (SOCCER SPL)

The crowd's indirect interaction with the Fish-Bird robots is transferred through direct human actors, whom read, interpret, comment on, or explain what is happening in the story. To isolate the crowd and study indirect collective interactions, we choose a domain with robot platforms that are only under indirect observation. Specifically, robot soccer as played in the Soccer SPL, which is part of the wider annual RoboCup competition for autonomous robotics [2], open to the public to watch. The Soccer SPL sees teams of 5-7 Nao V6 Humanoid robots, compete on a 10m x 7m soccer field to play fully autonomous soccer, depicted in Fig. 1. A unique feature of the league [15] is that every team must use the same robot platform, so that teams compete purely on their autonomous software. The only direct human involvement comes from referees who adjudicate the game. The physical form and soccer gameplay tend to attract large public crowds, with over 50,000 spectators attending RoboCup 2024 [16], who typically have limited experience in robotics and AI.

The Soccer SPL domain is ideal for studying HRI in the context of crowds. There are no mediating participants who communicate between the crowd and what is happening in the autonomous robots. Still, the crowd experiences a range of emotions while observing the game, similar to when crowds observe human soccer games. The crowds cheer and support the robots when they score, or when a goal-keeper saves a shot. This is particularly true for home team games, as shown in Fig. 1, where the Australian "yellow" team enjoyed strong support during the Sydney competition. Likewise, the crowd emotes in sympathy when things go wrong such as a robot falling over or narrowly missing a goal. In other cases the spectators shout in protest when the robots are penalised.

Unlike human soccer, Soccer SPL games have unique rules that can confuse non-expert crowds. These include managing robot falls, no offside rule, field restrictions like robots in the penalty box, and specific rules for kick-offs and free-kicks. Robots play under distinct conditions: limited audio use, restricted Wi-Fi communication, and referee decisions relayed via electronic signals. The robots' logic and capabilities also differ significantly from human expectations, adding to the challenge of understanding the game.

Crowd Affectivity and Soccer Spectatorship

The study of human crowd behaviour and spectatorship in soccer has long attracted research in social and sports psychology. Kerr *et al.* [17] examined the emotional effects of winning and losing, finding that losing team fans displayed more boredom, anger, and sulkiness. Other studies [18], [19] have focused on fan aggression and violence, while some explored emotional dynamics between spectators and players or among players themselves [20], [21]. Soccer and sports provide rich contexts for observing collective social emotions [22], supporting theories that emotions are inherently social [23]. Similarly, the Fish-Bird example presented in the previous section demonstrates how robotic narratives evoke empathy, fostering social engagement as human observers collectively respond to the emotional impact of the story.

We acknowledge the distinction between primal or basic emotions [24], [25] and higher-order, socially and culturally bound emotions [26]. Primal emotions arise quickly in response to stimuli, such as anger when a seat is stolen or joy when a favourite player scores. In the Soccer SPL context, fear and danger are mitigated, unlike scenarios where uncontrolled robots pose risks to spectators. Basic emotions like sadness, joy, excitement, and fear are immediate and instinctive [27]. In contrast, sports spectatorship often involves higher-order emotions that interweave with basic ones. For example, a new spectator may struggle to interpret key events in a game, leading to delayed or absent emotional responses. This illustrates higher-order emotional cognition [26], where event-emotion associations take longer to form.

Sports spectatorship involves emotions not only from watching the game but also from interacting with others. It is a sociocultural practice rooted in group identification and embodied reactions to those nearby. Emotional arousal in crowds can occur on three levels: (1) reaction to athletes' actions; (2) response to other spectators; and (3) understanding the game's progression [28]. In robot soccer, the cultural aspect lies in both sports as a cultural practice and robotics as part of human innovation. The evolving emotional engagement of robot soccer viewers is of particular interest. As a relatively new genre, emotional engagement may be limited. Table I compares emotional triggers in traditional and robotic soccer. Observations indicate a tendency toward negative emotions among new spectators due to unmet expectations, often driven by comparisons to human soccer. Bridging this gap requires systems that enhance spectators' understanding of the computational and predictive processes behind the game, fostering deeper emotional engagement.

TABLE I
COMPARISON OF EMOTIONAL TRIGGERS IN TRADITIONAL SOCCER VS. ROBOTIC SOCCER

Emotional Trigger	**Traditional Soccer**	**Robotic Soccer**
Player Persona and Backstory	Players often have distinct personalities, backstories, and narratives that fans can connect with emotionally.	Robots lack individuality and personal narratives, making it harder for audiences to form an emotional connection.
Physical and Emotional Expression	Human players exhibit visible emotional reactions (e.g., joy, frustration, or determination) during the game.	Robots generally do not display visible emotional states, reducing opportunities for empathic engagement.
Unpredictability and Human Error	Mistakes, improvisation, and unpredictability by human players evoke strong emotional responses.	Robotic soccer tends to prioritise precision and algorithmic decision-making, potentially reducing unpredictability.
Team Spirit and Collaboration	Team dynamics and chemistry among human players are often palpable and celebrated.	Robotic teams rely on pre-programmed strategies, with limited visible team dynamics or collaboration cues.
Crowd Engagement and Interaction	Human players actively engage with the audience (e.g., celebrating goals with fans).	Robots lack the ability to acknowledge or interact meaningfully with the crowd.
Aesthetic Skills and Creativity	Display of extraordinary skills (e.g., dribbling, feints) adds beauty and excitement to the game.	Robotic movements are often functional and lack the flair or creativity associated with human play.
Narratives and Rivalries	Stories of rivalries, underdog victories, and historic moments heighten emotional stakes.	Robotic soccer lacks comparable historical or personal narratives, reducing emotional depth.

TABLE II
AUTONOMY LEVELS (AL) OF HUMANOID ROBOTS IN ROBOCUP SOCCER BASED ON EXTERNAL SYSTEM INDEPENDENCE (ESI)

Autonomy Level	**External System Independence (ESI)**	**Description**
1	High Dependence	Robots fully reliant on human input; no autonomy, functioning as remote-controlled devices.
2	High Dependence	Limited autonomy; robots assist with basic functions like balance, still requiring significant human control.
3	Moderate Dependence	Robots can execute predefined tasks autonomously when prompted, but rely on external systems for complex decisions.
4	Moderate Dependence	Handle routine tasks autonomously but require external help for unpredictable or strategic scenarios.
5	Low Dependence	Robots make autonomous decisions in structured environments, relying minimally on external systems.
6	Low Dependence	Adapt to dynamic environments with occasional external input, managing complex in-game strategies.
7	Very Low Dependence	Mostly autonomous, collaborate with humans during critical moments, needing minimal external support.
8	Minimal Dependence	Independently manage chaotic environments, consulting external systems primarily for post-game analysis.
9	Complete Independence	Fully autonomous, integrating seamlessly with human players, learning and adapting without external input.

TABLE III
AUTONOMY LEVELS (AL) OF HUMANOID ROBOTS IN ROBOCUP SOCCER BASED ON ENVIRONMENTAL COMPLEXITY (EC)

Autonomy Level	**Environmental Complexity (EC)**	**Description**
1	Static	Simple, controlled environments; robots perform basic tasks with no dynamic elements.
2	Slightly Dynamic	Environments have minor changes; robots manage basic navigation with small, predictable obstacles.
3	Controlled Dynamic	Environments involve predictable dynamics, such as moving objects or players; robots begin to react to these elements.
4	Moderate Dynamic	Environments are more varied; robots must handle multiple dynamic elements like opponents and varying ball speeds.
5	Highly Dynamic	Complex, rapidly changing environments with unpredictable elements; robots need to continuously adapt to new conditions.
6	Semi-Unpredictable	Environments are highly dynamic with semi-unpredictable factors like varying player strategies; robots must anticipate and adapt.
7	Unpredictable	Environments are unpredictable, with frequent changes and unknowns; robots must make real-time decisions in complex scenarios.
8	Chaotic	Environments feature chaotic, almost random dynamics; robots operate with high adaptability and real-time strategy adjustments.
9	Extremely Chaotic	The highest level of environmental complexity; robots manage extreme unpredictability and continuous environmental changes autonomously.

IV. AUTONOMY LEVELS FOR UNMANNED SYSTEMS (ALFUS) FOR HUMANOID ROBOTS IN ROBOCUP SOCCER

The humanoid robots taking part in RoboCup Soccer can be considered unmanned ground vehicle (UGV) systems with the ultimate aim of autonomously executing complex tasks in a dynamic and competitive environment. These tasks include navigating the soccer field, interacting with other robots, making strategic decisions, and adapting to the ever-changing game conditions. The robots must work both individually and as part of a team, demonstrating not only advanced locomotion and manipulation capabilities but also sophisticated decision-making processes that mimic human players' tactical thinking. Additionally, these robots must engage in effective human-robot interaction, responding to human input from coaches, referees, and potentially even the audience, while maintaining a high level of independence from external control inputs. The goal is to advance the development of robotic systems that can operate autonomously in real-world, high-stakes scenarios,

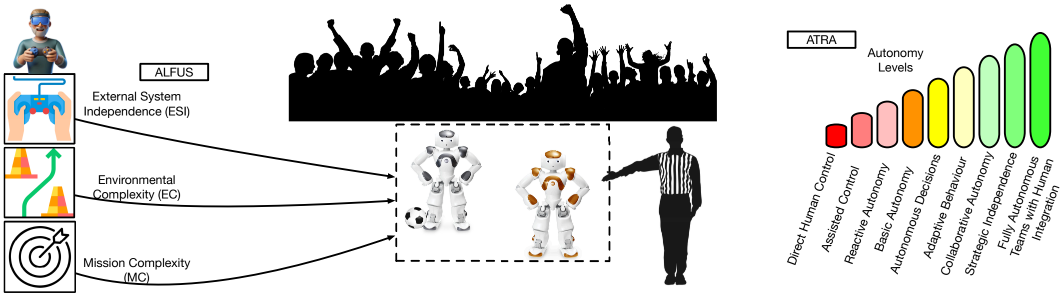

Fig. 2. The proposed framework, named the *Robot-Crowd Interaction Framework* (R-CIF), is based on the application of the ALFUS and ATRA methods to humanoid robots in RoboCup Soccer.

pushing the boundaries of what is possible in robotics.

When designing humanoid robots for RoboCup Soccer, it is crucial to assess their operational autonomy across several dimensions. These dimensions include environmental complexity (EC), which refers to the ability of the robots to navigate and function within a dynamic, unpredictable environment like a soccer field; mission complexity (MC), which involves the range and intricacy of tasks the robots must perform, such as coordinating with teammates, making strategic decisions, and adapting to opponent strategies; and external system independence (ESI), which measures the degree to which these robots can operate autonomously without relying on external systems or human operators. Based on these metrics, the so-called *Autonomy Levels For Unmanned Systems* (ALFUS) framework [29] can be adopted and applied to provide a more in-depth overview for the design of humanoid robots for RoboCup Soccer, as shown in Fig. 2. Regarding external system independence (ESI), a spectrum of autonomy levels (AL) can be defined as shown in Table II. Concerning the environmental complexity (EC), different AL can be identified according to gradually increased complexity, as shown in Table III. With reference to mission complexity (MC), various AL can be outlined according to gradually increased complexity, as shown in Table IV.

V. AUTONOMY AND TECHNOLOGY READINESS ASSESSMENT (ATRA), AND HUMAN-ROBOT INTERACTION IN ROBOCUP SOCCER

To systematically evaluate the Autonomy Levels (AL) of humanoid robots taking part in RoboCup Soccer, the *Autonomy and Technology Readiness Assessment* (ATRA) framework [30] may be adopted, as shown in Fig. 2. The ATRA framework combines both ALs and Technology Readiness Level (TRL) metrics. Borrowing the idea from similarly demanding robotics systems, such as snake robots [31], the same framework can be used to provide a comprehensive picture of how humanoid Soccer SPL robots may achieve the desired goals. In the following, a nine-level scale framework is proposed based on the gradual increase (autonomy as a gradual property) of guidance, navigation, and control (GNC) functions and capabilities. The proposed framework is named *Robot-Crowd Interaction Framework* (R-CIF).

TABLE IV
AUTONOMY LEVELS (AL) OF HUMANOID ROBOTS IN ROBOCUP SOCCER BASED ON MISSION COMPLEXITY (MC)

Autonomy Level	**Mission Complexity (MC)**	**Description**
1	Basic Movements	Robots perform simple actions such as standing, sitting, or basic walking without any specific goal.
2	Simple Task Execution	Robots complete straightforward tasks, such as moving toward a stationary ball or kicking it in a straight line.
3	Basic Interaction	Robots engage in elementary interactions, like kicking a moving ball or passing it to a teammate in a predictable manner.
4	Coordinated Task Execution	Robots carry out coordinated actions with teammates, such as passing the ball back and forth or moving in formation.
5	Tactical Play	Robots begin to implement simple strategies, like deciding when to pass or shoot based on the positions of teammates and opponents.
6	Dynamic Role Adaptation	Robots adapt their roles dynamically during the game, switching between offense and defense based on the evolving situation.
7	Complex Strategy Implementation	Robots execute complex, multi-step strategies, like orchestrating coordinated attacks or defensive maneuvers in response to the opponent's actions.
8	Autonomous Game Management	Robots manage all aspects of gameplay autonomously, including strategic decisions, role assignments, and on-the-fly adaptations to game dynamics.
9	Strategic and Long-Term Planning	Robots not only manage immediate gameplay but also engage in long-term planning, learning from previous matches and adapting strategies over time.

1. Direct Human Control

- **ESI:** Full Dependence on External Systems.
- **EC:** Very Low (Static, controlled environment).
- **MC:** Very Low (Basic movements, such as standing or sitting).
- **HRI:** Full human control; robots follow exact human commands with no autonomy.
- **Roles of Actors Involved:**
  - **Humans Controlling Robots:** Directly teleoperate robots using remote controls or software interfaces,

making all decisions.
  - **Audience:** Primarily passive, watching the operators control the robots, with no direct robot interaction.
  - **Referees:** Focus on evaluating human performance and rule adherence, as robots execute only basic movements.
  - **Crowd HRI:** Minimal or non-existent; robots do not respond to audience cues.

2. Assisted Human Control

- **ESI:** High Dependence on External Systems.
- **EC:** Low (Controlled environment with minor dynamic elements).
- **MC:** Low (Simple tasks like moving towards a ball).
- **HRI:** Human operators provide continuous commands, with minimal robot autonomy.
- **Roles of Actors Involved:**
  - **Humans Controlling Robots:** Provide direct inputs but benefit from simple automated assistance (e.g., balancing, basic obstacle avoidance).
  - **Audience:** Observes with some involvement, influencing minor, non-critical robot behaviours.
  - **Referees:** Primarily judge human decisions and rule compliance, starting to include simple robot actions.
  - **Crowd HRI:** Limited, but possible through indirect interactions.

3. Reactive Autonomy

- **ESI:** Moderate Dependence on External Systems.
- **EC:** Low to Moderate (Slightly dynamic environment).
- **MC:** Low (Basic tasks with minor decision-making, like kicking a ball when close).
- **HRI:** Robots react to human inputs with pre-programmed responses.
- **Roles of Actors Involved:**
  - **Humans Controlling Robots:** Provide high-level commands while robots execute predefined responses autonomously, such as moving to a ball.
  - **Audience:** Engages more actively, potentially using crowd noise to influence robot behaviour indirectly (e.g., robots could respond to loud cheers).
  - **Referees:** Begin focusing on the fairness of robot responses to human inputs, ensuring that robots act within set rules autonomously.
  - **Crowd HRI:** Interaction is still basic, but robots might perform simple gestures in response to audience actions, enhancing the viewing experience.

4. Basic Autonomous Behaviour

- **ESI:** Moderate Dependence on External Systems.
- **EC:** Moderate (Dynamic environment with predictable patterns).
- **MC:** Moderate (Basic gameplay, such as passing the ball in a predictable manner).
- **HRI:** Robots execute predefined actions autonomously; humans oversee and intervene when necessary.
- **Roles of Actors Involved:**
  - **Humans Controlling Robots:** Supervise and intervene as needed, but robots handle routine actions like passing or moving to open spaces autonomously.
  - **Audience:** More engaged, potentially influencing certain robot decisions, such as encouraging a shot on goal through synchronised cheers.
  - **Referees:** Shift focus toward ensuring robots comply with soccer rules autonomously, monitoring fairness and accuracy of robot actions.
  - **Crowd HRI:** Robots may recognise crowd noise and adjust performance (e.g., increased speed or precision under loud cheers), starting to reflect team collectivism influenced by audience support.

5. Autonomous Decision-Making in Structured Scenarios

- **ESI:** Low Dependence on External Systems.
- **EC:** Moderate to High (Dynamic environment with increasing unpredictability).
- **MC:** Moderate (Coordinated team play, basic adaptation to opponents).
- **HRI:** Robots make autonomous decisions in structured scenarios. Humans intervene only in complex situations.
- **Roles of Actors Involved:**
  - **Humans Controlling Robots:** Shift to a supervisory role, only give strategic decisions in complex scenarios; robots manage the flow of play autonomously.
  - **Audience:** More interactive crowd participation that can influence non-critical elements, such as choosing which robot takes a free kick through live voting.
  - **Referees:** Primarily assess the autonomous decision-making of robots, focusing on rule adherence and ensuring fairness in increasingly complex gameplay.
  - **Crowd HRI:** Robots may modify their gameplay from crowd input, with collective team behaviour possibly reinforced by audience support (e.g., a "boost" in team performance from audience cheers).

6. Adaptive Team Behaviour

- **ESI:** Low Dependence on External Systems.
- **EC:** High (Dynamic, semi-unpredictable environment).
- **MC:** High (Dynamic role adaptation within the team, complex gameplay strategies).
- **HRI:** Robots adapt strategies based on real-time game conditions. Humans focus on high-level oversight.
- **Roles of Actors Involved:**
  - **Humans Controlling Robots:** Focus on high-level strategy, allowing robots to handle dynamic role adaptations and in-game decisions.
  - **Audience:** Acts as a strategic motivator; they can influence the mood or intensity of the robots' play, simulating crowd energy's effect on human players.
  - **Referees:** Monitor and validate complex, adaptive robot behaviours, ensuring autonomous decisions comply with evolving game rules.

  - **Crowd HRI:** Interaction is more advanced, with robots recognising specific crowd patterns (e.g., chants or waves) and using them to trigger team-level tactical changes, reinforcing team collectivism through collective crowd influence.

7. Collaborative Autonomy with Human Interaction

- **ESI:** Very Low Dependence on External Systems.
- **EC:** High (Unpredictable environment with varied dynamics).
- **MC:** High (Coordinated gameplay with complex decision-making and adaptation).
- **HRI:** Robots collaborate and communicate with humans and each other. Humans provide strategic input or interact during critical moments.
- **Roles of Actors Involved:**
  - **Humans Controlling Robots:** Serve as tactical advisors or "coaches," giving strategic inputs that robots incorporate into real-time decision-making.
  - **Audience:** More interactively, with crowd behaviour potentially influencing tactical decisions (e.g., calling for a defensive or offensive stance).
  - **Referees:** Engage in more complex rule enforcement, interacting with robots directly to resolve disputes or clarify rules during gameplay.
  - **Crowd HRI:** Robots display high levels of responsiveness to crowd dynamics, using collective crowd behaviour to adjust strategies, enhancing the link between audience support and team performance.

8. Strategic Independence

- **ESI:** Minimal Dependence on External Systems.
- **EC:** Very High (Highly unpredictable environment, possibly chaotic).
- **MC:** Very High (Full team autonomy with strategic decision-making and real-time adaptation).
- **HRI:** Robots operate with strategic independence, only consulting humans for post-match analysis or learning.
- **Roles of Actors Involved:**
  - **Humans Controlling Robots:** Mostly hands-off during matches, focusing on pre- and post-game analysis, with robots being independent during play.
  - **Audience:** Plays an influential role indirectly; robots might learn from crowd reactions to improve future strategies or even alter gameplay in real-time based on audience energy levels.
  - **Referees:** Focus on high-level strategic rule enforcement, possibly interacting with robots post-match for rule clarification and future learning.
  - **Crowd HRI:** Robots might analyse crowd energy to dynamically adjust gameplay, giving deep integration of crowd influence in real-time decisions, mimicking the way human teams feed off crowd energy.

9. Fully Autonomous Teams with Human Integration

- **ESI:** Complete Independence from External Systems.
- **EC:** Extremely High (Chaotic, unpredictable environment).
- **MC:** Extremely High (Complex and evolving game scenarios, long-term strategy learning).
- **HRI:** Robots integrate into human teams, learning and adapting from human players and the environment.
- **Roles of Actors Involved:**
  - **Humans Controlling Robots:** Act as equals or even teammates, with robots learning and evolving alongside human players, adapting in real-time and over multiple games.
  - **Audience:** Integral to the game, possibly influencing robots' learning algorithms, helping shape team dynamics and strategies through crowd behaviour.
  - **Referees:** Engage in dynamic, real-time rule enforcement and discussions directly with robots, ensuring fair play in an environment where robots operate at human-like autonomy levels.
  - **Crowd HRI:** Robots interact with the crowd as with human teammates, integrating real-time crowd feedback into gameplay and strategy, reinforcing a deep sense of team collectivism where robots and humans collaborate seamlessly on and off the field.

VI. CASE STUDY

A. Applicability of the Robot-Crowd Interaction Framework (R-CIF)

To address the applicability of the proposed framework, R-CIF, and enhance its clarity, we discuss an illustrative real-world example inspired by RoboCup Soccer dynamics. This example aims at demonstrating how the selected ALFUS framework and the ATRA method can be applied in practice. Referring to Fig. 3, in a RoboCup Soccer match, consider a scenario where a humanoid robot goalkeeper malfunctions mid-game, leaving the goal undefended. Using the ALFUS framework, we assess how robots on the team adapt to this high-stakes situation. Robots with higher mission complexity capabilities might autonomously reassign roles, with a defender temporarily taking over as the goalkeeper. This scenario highlights the adaptability enabled by increased autonomy and showcases how external system independence (ESI) plays a crucial role in ensuring seamless gameplay continuity.

B. Communicating Inner-System Autonomy Processes to a Crowd

To bridge the gap between robotic autonomy processes and spectator comprehension, we propose potential communication strategies that leverage multi-modal interaction techniques. These methods aim to enhance engagement and foster a deeper understanding of inner-system decision-making processes. The idea is illustrated on the right side of Fig. 3.

1) Visual Storytelling Techniques: Dynamic screen visualisations can be employed to illustrate the robots' autonomy mechanisms in real-time. For instance, visual overlays can display key decision-making processes such as role reassignment during unexpected scenarios (e.g., a defender temporarily

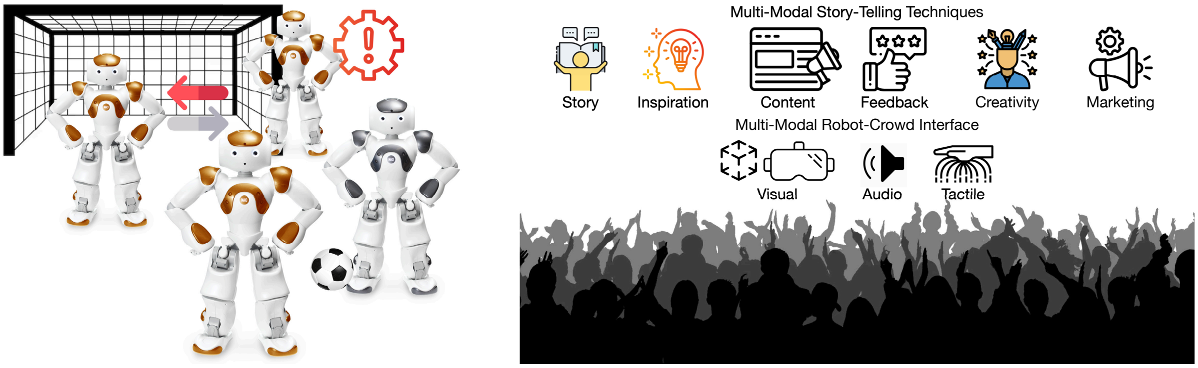

Fig. 3. A schematic rendering illustrating the RoboCup soccer scenario where the goalkeeper malfunctions mid-game. It highlights how the team dynamically adapts by reassigning roles, focusing on mission complexity (MC), environmental complexity (EC), and external system independence (ESI). On the right side of the figure, potential multi-modal story-telling techniques are illustrated for communicating inner-system autonomy processes to a crowd.

assuming the goalkeeper's role). These visualisations can be projected on large displays or integrated into live broadcasts to provide clear and intuitive insights into robot behaviours. Extended Reality (XR) technologies, encompassing Virtual Reality (VR), Mixed Reality (MR) and Augmented Reality (AR), present possible ways to immerse spectators in the robots' operational environment. VR experiences could transport users into a simulated perspective of the robot's sensory world, offering a first-hand understanding of autonomy mechanisms. On the other hand, through MR/AR applications, spectators can use handheld devices or wearables to view overlays of robots' decision-making processes superimposed on the physical field.

2) Audio-Enhanced Storytelling Techniques: Audio commentary, either live or AI-generated, can play a critical role in communicating complex robotic processes in a narrative format. Commentators can explain the rationale behind key decisions, such as strategy shifts or adjustments to environmental complexity. The use of spatial audio techniques could further enhance the storytelling experience by associating audio cues with specific events or areas on the field.

3) Tactile Feedback with Haptics: Haptic technology offers a unique approach to making robotic processes tangible for spectators. Interactive installations equipped with haptic devices could allow users to feel physical feedback corresponding to the robots' movements or decisions. For example, a haptic interface might simulate the impact of a robot colliding with an opponent or the subtle vibrations of internal decision-making processes.

4) Integration of Multi-Modal Techniques: A holistic approach integrating visual, audio, and tactile methods would provide a comprehensive spectator experience. For example, a system combining real-time screen visualisations with AR overlays, live audio commentary, and haptic feedback could offer an immersive understanding of robotic autonomy.

The proposed multi-modal storytelling integrates story, inspiration, content, feedback, creativity, and marketing to create an educational and emotionally engaging experience. This approach enhances public engagement and makes system autonomy processes accessible and meaningful in public spaces.

VII. CONCLUSIONS

This paper examined parallels between human and robotic sports spectatorship, focusing on RoboCup Soccer Standard Platform League (SPL). Through the lens of Human-Robot Interaction (HRI), we explored how autonomous robots evoke emotions and foster engagement, similar to human athletes. Using the Autonomy Levels for Unmanned Systems (ALFUS) framework, we assessed how interaction complexity enhances spectators' emotional involvement. The Autonomy and Technology Readiness Assessment (ATRA) method provided a structured approach for improving robot capabilities, addressing challenges, and advancing autonomy. Based on these establish methodology, a conceptual framework for crowd-robot interaction, referred to as the *Robot-Crowd Interaction Framework* (R-CIF) was introduced. A case study was also discussed to enhance methodology clarity with a real-world example. Potential methods for communicating inner-system autonomy processes to a crowd were also outlined. One fundamental target of this paper is to further increase global efforts to realise the large variety of possible applications offered by HRI and crowd engagement, and to provide an up-to-date position paper as a stepping-stone for new research and development. We emphasise the need for further research into how to design robot behaviours to resonate with human emotions in a collective setting. Future work will need to develop frameworks that measure real-time audience affectivity during robot competitions, and innovative techniques for engagement, such as Extended Reality (XR) solutions, including Virtual reality (VR), Mixed Reality (MR), and Augmented Reality (AR), or multi-modal experiences (e.g., soundscapes, haptic feedback, maybe even smell) to enhance immersion and understanding [32]–[34]. This will involve capturing and analysing empirical audience data, such as crowd noise, facial expressions, and post-match surveys, to correlate spectator reactions with in-game events and validate the proposed framework.

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