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Drones in Sports

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ABSTRACT

Drones, also known as unmanned aerial vehicles (UAVs), have emerged as one of the most innovative technologies transforming the sports industry. A drone is an aircraft that operates without a human pilot on board. Drones can be controlled remotely or programmed to fly autonomously using advanced technologies such as artificial intelligence (AI), global positioning systems (GPS), sensors, and computer vision. Their ability to capture aerial images, monitor activities, collect data, and reach difficult locations has made them valuable tools for athletes, coaches, referees, broadcasters, and sports organizations. How drones are used in sports is a fascinating topic that showcases the intersection of technology and athleticism. Drones are increasingly being used in the sports industry to improve performance analysis, broadcasting, training, event management, and spectator experiences. As drone technology continues to advance, its influence on the sports industry is expected to increase significantly. Drones will be everywhere in the future. Sports will also see big changes following this trend. In this paper, we will explore the different ways in which drones are used in modern sports.

KEYWORDS: *drones, unmanned aircrafts, unmanned aerial vehicles (UAVs), unmanned aircraft systems (UAS), sports, sports industry, entertainment.*

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INTRODUCTION

Drones have made a significant impact in various industries, and the world of sports is no exception. With their aerial capabilities and advanced technology, drones have revolutionized the way sporting events are recorded, analyzed, and even played. Drones are rapidly transforming the sports industry by introducing innovative ways to capture events, monitor athletes, improve training, enhance security, and engage spectators. The integration of drones into sports has revolutionized how sporting events are organized, monitored, analyzed, and presented to audiences. From football and soccer to skiing, cycling, athletics, and motorsports, drones provide unique perspectives and capabilities that traditional technologies cannot easily achieve. They are used for live broadcasting, athlete performance analysis, training, event security, and even competitive racing. As emerging technologies continue to advance, drones are expected to play an increasingly important role in shaping the future of sports. Their future development will be influenced by improvements in artificial intelligence, autonomous navigation, computer vision, battery technology, data analytics, and communication networks [1].

WHAT IS A DRONE?

At least three terms are used to describe drones, depending on how they are operated. The terms include Unmanned Aerial Vehicles (UAVs), Unpiloted Aircraft System (UAS), and Remote Piloted Aircraft System (RPAS). The FAA defines drones, also known as unmanned aerial vehicles (UAVs), as any aircraft system without a flight crew onboard. Drones include flying, floating, and other devices, including unmanned aerial vehicles (UAVs), that can fly independently along set routes using an onboard computer or follow commands transmitted remotely by a pilot on the ground. A typical drone is shown in Figure 1 [2]. A drone is usually controlled remotely by a human pilot on the ground, as typically shown in Figure 2 [3]. Drones can range in size from large military drones to smaller drones. Drones,

previously used for military purposes, have started to be used for civilian purposes since the 2000s. Since then, drones have continued to be used in intelligence, aerial surveillance, search and rescue, reconnaissance, and offensive missions as part of the military Internet of things (IoT). Today, drones are used for different purposes such as aerial photography, surveillance, agriculture, entertainment, healthcare, transportation, law enforcement, etc.

Drones work much like other modes of air transportation, such as helicopters and airplanes. When the engine is turned on, it starts up, and the propellers rotate to enable flight. The motors spin the propellers and the propellers push against the air molecules downward, which pulls the drone upwards. Once the drone is flying, it is able to move forward, back, left, and right by spinning each of the propellers at a different speed. Then, the pilot uses the remote control to direct its flight from the ground [4],

Drone laws exist to ensure a high level of safety in the skies, especially near sensitive areas like airports. They also aim to address privacy concerns that arise when camera drones fly in residential areas. These include the requirement to keep your drone within sight at all times when airborne. In the United States, drones weighing less than 250g are exempt from registration with civil aviation authorities. If your drone exceeds 250g in weight, you will also require a Flyer ID, which requires passing a test [5]. It is necessary to register as an operator, be trained as a pilot, and have civil liability insurance, in addition to complying with various flight regulations, and those of the places where their use is permitted.

Most drones have a limited payload, usually under 11 pounds. Drones are classified according to their size. Here are the different drone types:

- Nano Drone: 80-100 mm
- Micro Drone: 100-150 mm
- Small Drone: 150-250 mm
- Medium Drone: 250-400 mm
- Large Drone: 400+ mm

One of the emerging trends in drone use for factories is the utilization of LiDAR technology. LiDAR stands for Light Detection and Ranging. This technology provides accurate depth information essential for understanding the three-dimensional structure of the environment. LiDAR sensors emit laser beams to measure distances to objects, creating high-resolution 3D maps of the surrounding terrain and objects. The ability to capture detailed data through LiDAR technology has opened up opportunities for better predictive maintenance, reduction in inspection times, and overall cost savings [6].

DRONES IN SPORTS

Drones have become an important emerging technology in the sports industry, offering new opportunities for broadcasting, athlete training, performance analysis, event management, security, and facility maintenance. Their ability to capture aerial footage, monitor large areas, and collect valuable information has transformed many aspects of sporting activities. The emergence of drone racing demonstrates that drone technology can create entirely new forms of competitive sports. Ultimately, drones are likely to become an increasingly valuable part of the sports technology ecosystem. Rather than completely replacing traditional cameras, coaches, referees, or security personnel, they will primarily complement existing systems by providing new perspectives. With responsible innovation and continued technological progress, drones have the potential to make the future of sports more efficient, engaging, accessible, and technologically advanced [1]. Figure 3 is a representation of drones in sports [7].

While many drones in sports are busy capturing the action from above, a completely new sport has exploded onto the scene—one where the drones themselves are the stars of the show. Drones are transforming how fans experience the Olympic Games. From high-speed downhill skiing to spectacular opening ceremony light shows, unmanned aerial technology is now a key part of modern Olympic production.

APPLICATIONS OF DRONES IN SPORTS

Drones are transforming how sporting events are organized, monitored, analyzed, and presented to audiences. They have emerged as valuable technological tools with diverse applications in the sports industry. Their uses include sports broadcasting, athlete training, tactical analysis, event security, officiating support, outdoor sports monitoring, facility inspection, marketing, search and rescue, environmental monitoring, and scientific research. Common applications of drones in sports therefore include the following [1,7-9]:

- *Aerial Photography*: One of the most important applications of drones in sports is aerial photography and videography. Traditionally, sports broadcasters relied on stationary cameras, helicopters, and cable-mounted camera systems to capture sporting events. Although these methods remain useful, drones offer greater flexibility and can capture dynamic footage from different heights and angles. Equipped with high-resolution cameras and stabilization systems, drones can follow athletes, record sporting activities, and

provide panoramic views of stadiums and outdoor venues. Their ability to move rapidly and change direction makes them particularly useful for recording fast-moving sporting activities. Figure 4 shows a drone capturing sports events [10].

- *Athlete Training*: Another significant application of drones is athlete training and performance analysis. Coaches and trainers use drones to observe athletes from above and evaluate their movements, positioning, coordination, and tactical decisions. In soccer, for example, drones can record training sessions and provide an aerial view of player formations, passing patterns, defensive structures, and team movements. This perspective helps coaches identify tactical weaknesses and develop strategies for improving team performance. Figure 5 shows how drones are used for athlete training [2].
- *Recording Events*: One of the most common and obvious uses of drones in sports is recording sporting events. Drones equipped with high-resolution cameras can capture breathtaking footage of the action from unique vantage points. Gone are the days when we relied solely on fixed cameras and manned helicopters to capture the intensity and excitement of sporting moments. Drones allow broadcasters and spectators alike to experience the thrill of the game from a whole new perspective, providing a more immersive viewing experience.
- *Drone Racing:* Another growing application is drone racing, which has developed into a competitive sport. Drone racing involves pilots controlling high-speed drones through specially designed courses containing obstacles, gates, and challenging turns. Many competitions use first-person-view (FPV) technology, allowing pilots to see real-time video transmitted from cameras mounted on their drones. This creates an immersive experience that requires excellent hand-eye coordination, rapid decision-making, and technical expertise. Drone racing combines elements of aviation, robotics, electronics, and competitive gaming, attracting participants interested in both sports and emerging technologies.
- *Facility Inspection:* Drones have applications in sports facility inspection and maintenance. Stadiums, arenas, golf courses, ski resorts, and large recreational facilities require regular inspection to maintain safety and operational efficiency. Drones equipped with cameras and specialized sensors can inspect stadium roofs, lighting structures, scoreboards, and other difficult-to-access areas. Golf course managers can use drones to assess turf conditions, drainage problems, and landscape maintenance needs. Similarly, ski resort operators may use drones to inspect slopes and identify hazards. These applications can reduce inspection time, improve safety, and lower maintenance costs.
- *Sports Marketing*: Sports organizations increasingly use drones for marketing, advertising, and promotional activities. Aerial photographs and videos can showcase sporting venues, highlight major events, and create visually engaging promotional materials. For example, professional sports teams can use drone footage to produce promotional videos featuring stadiums, training facilities, and community events. Golf resorts can use aerial photography to display the layout and natural beauty of their courses. Sports organizations can combine drone recordings with graphics, music, commentary, and digital effects to create compelling promotional campaigns.
- *Search and Rescue:* Drones can support search-and-rescue operations during outdoor sporting activities, particularly those conducted in remote or hazardous environments. Events such as mountain marathons, trail running competitions, sailing races, and endurance cycling may expose athletes to difficult terrain and unpredictable weather. When participants become injured, lost, or stranded, appropriately equipped drones can assist rescue teams by surveying large areas and identifying possible locations of individuals requiring assistance.
- *Sports Research:* Drones provide valuable opportunities for scientific research in sports. Researchers can use aerial video recordings and sensor-based systems to study athlete movement, team behavior, and performance under different conditions. In sports biomechanics, drone recordings may supplement conventional camera systems by providing additional perspectives on body movement. In team sports research, aerial footage can help researchers analyze player spacing, movement patterns, and tactical coordination. Drones can also support studies involving outdoor endurance sports by recording athlete movement across selected portions of a course. Nevertheless, accurate scientific analysis requires appropriate calibration, reliable measurement methods, and careful consideration of environmental factors. Drone recordings alone may not provide the precision needed for every biomechanical measurement.

- *Sports Journalism*: Drones have also had a significant impact on sports journalism. Journalists can use drones to capture footage for their articles, providing readers with a visual representation of the game or event being reported. This adds depth and context to the written content, making it more engaging and informative. Drones can also be used to cover sports events from various angles simultaneously, allowing journalists to capture multiple perspectives and provide a comprehensive overview of the action. This versatility and agility make drones an invaluable tool for sports journalists, enabling them to deliver compelling stories to their readers. Figure 6 shows football game drone [11].
- *Sports Broadcasting*: The integration of drone technology in sports broadcasting has taken off, demonstrating its versatility across various major events. Drones are changing sports broadcasting by offering unique camera angles and real-time dynamic footage that enhances the viewer's experience. You will see fast-paced action from perspectives previously unavailable, capturing both wide shots and detailed close-ups. This innovative technology engages audiences more effectively, with a significant number of fans expressing a desire for more drone footage. Drones also provide valuable data, like player performance metrics, during live events, making broadcasts more informative and immersive. They are already being utilized in major sporting events, showcasing their growing role. Figure 7 shows the use of drones in sports broadcasting [9].
- *Filming Sports*: The arrival of drone technology has completely revolutionized filming sports. Drones, which can be accommodated even in indoor spaces, make it easier to record sports events without hassle. Filming sports has become so much easier with drones, whether in an indoor game like a badminton match or an outdoor football match. Filming with drones has provided a lot of benefits to professional videographers. With this dynamic filming, the costs are significantly reduced. Figure 8 displays a drone for filming sports [12].

BENEFITS

Drones offer numerous benefits to the sports industry by improving athlete training, enhancing sports broadcasting, supporting tactical analysis, strengthening event security, and increasing operational efficiency. The major advantage of drones lies in their ability to provide flexible aerial perspectives, collect useful information, and operate in environments where conventional observation methods may be limited. Other benefits of drones in sports therefore include the following [1,9]:

- *Improved Performance:* One of the most significant benefits of drones in sports is their ability to improve athlete training and performance. Drones equipped with high-resolution cameras can record athletes from different angles, providing coaches with valuable information about their movements, techniques, positioning, and overall performance. Unlike traditional ground-based cameras, drones can capture aerial views that reveal patterns and details that might otherwise go unnoticed. By providing comprehensive visual information, drones enable coaches to make better-informed decisions, correct technical mistakes, and develop personalized training programs. This contributes to improved athletic performance and more effective preparation for competitions.
- *Better Game Strategy*: Another important benefit of drones in sports is their contribution to tactical analysis and strategic planning. Coaches and sports analysts can use aerial recordings to study team formations, player movements, spatial relationships, and tactical decisions. In football, aerial footage can reveal how players maintain defensive formations, create attacking opportunities, and respond to opponents' movements. In rugby, drones can help coaches examine team positioning during attacking and defensive situations. In soccer, drones can provide a broad view of player distribution across the field, allowing coaches to identify gaps and evaluate tactical organization. These technologies can help coaches develop strategies based on observable evidence rather than relying entirely on personal judgment. Consequently, drones support more accurate tactical evaluations, better game preparation, and improved decision-making during training.
- *Increased Safety and Security:* Safety and security are major concerns in sports, particularly during large events that attract thousands of spectators. Drones can help event organizers and security personnel monitor stadium surroundings, parking areas, entrances, exits, and other important locations. Equipped with cameras and appropriate sensors, drones can provide aerial surveillance that helps security teams identify overcrowding, unauthorized access, unusual activities, and potential safety hazards. During marathons, cycling races, and outdoor sporting events, drones

can monitor extensive routes that would otherwise require numerous security personnel. Drones may also assist emergency response teams by providing aerial information about accidents, crowd movements, and difficult-to-access locations.

- *Cost-effective Photography*: Traditional aerial sports photography often requires helicopters, cranes, elevated camera platforms, or specialized equipment. Such methods can be expensive, logistically complicated, and difficult to deploy in certain environments. Drones provide a comparatively affordable and flexible alternative for many aerial photography and videography tasks. They can be deployed relatively quickly, operate at different heights, and capture footage from various perspectives. Although professional drones require investment in equipment, maintenance, insurance, trained operators, and regulatory compliance, they can reduce production expenses in suitable applications. This cost advantage makes aerial photography more accessible to smaller sports organizations and creates opportunities for high-quality visual content production.
- *Enhanced Safety*: Drones can contribute to athlete safety by helping coaches and sports professionals observe training conditions and identify potentially hazardous situations. In outdoor sports such as skiing, mountain biking, surfing, and cycling, drones can provide aerial views of terrain, obstacles, weather-related hazards, and difficult-to-access locations. Coaches and event officials can use this information to assess training environments and identify possible risks. Drones may also support injury-prevention efforts by recording athletic movements for subsequent analysis. Coaches and qualified sports professionals can examine these recordings to identify potentially problematic techniques or movement patterns.
- *Improved Fan Engagement*: Spectators are central to the success of the sports industry. Drones can enhance the spectator experience by providing exciting visual content, aerial event coverage, and engaging promotional materials. During sporting events, drone footage can be incorporated into television broadcasts, stadium displays, highlight videos, and digital media platforms. Fans can enjoy broader perspectives of venues and selected sporting activities. Drones can also be used to create memorable opening sequences, event presentations, and post-competition highlights. By making sports coverage more visually engaging, drones can strengthen fan interest and encourage greater participation in sporting activities.
- *Sustainability:* Drones can support environmentally responsible practices in sports by improving monitoring efficiency and reducing the need for certain resource-intensive operations. In outdoor sporting events, aerial surveys can assist organizers in assessing environmental conditions, identifying damaged areas, and planning routes that minimize unnecessary disturbance. Drones equipped with suitable imaging technologies may also help groundskeepers identify areas of vegetation stress or irrigation problems, supporting more efficient maintenance.

CHALLENGES

Although drones offer significant benefits, their adoption also introduces challenges related to safety, privacy, regulations, weather conditions, technical limitations, and operational costs. Other challenges of drones in sports therefore include the following [1,13]:

- *High Costs*: Although drones can improve efficiency in sports, acquiring, and maintaining advanced drone systems can be expensive. Professional drones equipped with high-resolution cameras, thermal imaging devices, advanced sensors, and AI-powered analytical software may require substantial investment. Additional expenses include batteries, replacement parts, software subscriptions, insurance, maintenance, and operator training. Sports organizations may also need specialized personnel to operate drones and analyze the collected information. For smaller clubs, schools, and community sports organizations, these costs may be difficult to justify. Consequently, the financial requirements associated with drone technology can create inequalities between wealthy sports organizations and those with limited resources.
- *Privacy Concerns*: Privacy is a significant challenge associated with drones in sports. Drones equipped with powerful cameras can capture detailed images and videos of athletes, coaches, spectators, and other individuals without their knowledge or consent. During training sessions, drones may record confidential team strategies, private conversations, or sensitive information about athletes. Such information could be misused if it falls into unauthorized hands. Sports organizations must therefore develop clear privacy policies governing the collection, storage, sharing, and use of drone-

generated information. Obtaining appropriate consent and complying with applicable privacy laws are essential for protecting individual rights.

- *Ethical Concerns*: The use of drones raises ethical questions concerning fairness, transparency, and equal access to technology. Wealthy sports teams may have access to sophisticated drones and advanced analytical systems, while smaller organizations may lack the resources to purchase similar equipment. This technological imbalance could create competitive advantages unrelated to athletic ability. Drones may also be used improperly to observe opponents' training sessions or gather confidential tactical information. Such activities could undermine sportsmanship and violate competition rules. Sports governing bodies must establish ethical guidelines to ensure that drone technology supports fair competition rather than providing opportunities for exploitation.
- *Safety Risks*: One of the major challenges of using drones in sports is the risk of accidents and injuries. Sports activities often involve large crowds, fast-moving athletes, and unpredictable movements. A malfunctioning drone could collide with athletes, spectators, officials, or sports equipment, resulting in serious injuries. For example, a drone operating above a football stadium could lose control because of mechanical failure, communication problems, or operator error. Falling drones may also damage stadium facilities and expensive sports equipment. Although modern drones have obstacle detection systems and emergency landing capabilities, these technologies cannot eliminate every risk. Sports organizations must establish strict safety procedures, maintain appropriate flight distances, and ensure that drone operators receive adequate training.
- *Regulations*: The operation of drones in sports is subject to aviation regulations and legal restrictions that vary across countries and regions. In the United States, the Federal Aviation Administration (FAA) regulates drone operations, including many commercial activities. Drone operators may need appropriate certification, authorization, and compliance with airspace restrictions. Flying over crowds, near airports, or around certain stadiums can be prohibited or subject to additional requirements. These regulations can limit the flexibility of sports organizations wishing to use drones for broadcasting, training, or event management. International competitions present additional difficulties because drone operators must understand and comply with the laws of different countries. Failure to follow regulations can result in penalties, legal disputes, and suspension of drone operations.
- *Limited Battery Life*: Battery limitations represent a major technical challenge for drones in sports. Most small commercial drones can operate for only a limited period before requiring battery replacement or recharging. This becomes problematic during sporting events that last several hours, such as football tournaments, cycling competitions, marathons, and motorsport races. Continuous aerial coverage may require multiple drones, additional batteries, and carefully coordinated flight schedules.
- *Cybersecurity:* Cybersecurity is an increasingly important concern as drones become more connected to digital platforms and cloud-based analytical systems. Unauthorized individuals may attempt to interfere with drone communications, access stored video footage, or steal sensitive information. Cyberattacks could compromise confidential training strategies, athlete performance data, or broadcasting operations. Sports organizations must therefore implement strong cybersecurity measures, including encrypted communications, secure authentication, software updates, and controlled access to collected data. Protecting drone systems against cyber threats is essential for maintaining operational reliability and public confidence.
- *Skills Gap*: Effective drone operations require specialized knowledge and practical skills. Operators must understand aviation regulations, flight control systems, camera positioning, emergency procedures, and the particular demands of sporting environments. Capturing high-quality footage of fast-moving athletes can be especially challenging because operators must maintain appropriate distances while adjusting to sudden changes in direction and speed. Sports organizations may struggle to recruit qualified personnel or provide adequate training for existing staff. Investment in professional training and certification is therefore necessary for successful drone integration.
- *Integration*: Integrating drones with existing sports technologies can present additional challenges. Modern sports organizations already use video analysis systems, wearable sensors, electronic scoreboards, tracking devices, and performance management platforms. Drone-generated information must be compatible with

these systems to provide meaningful insights. Differences in software formats, communication protocols, and data processing methods may complicate integration. Organizations may need to upgrade their technological systems before fully benefiting from drone applications. These integration requirements can increase costs and delay implementation.

- *Resistance*: The introduction of drones into sports may encounter resistance from athletes, spectators, coaches, and event organizers. Some individuals may perceive drones as intrusive surveillance devices, while others may worry about accidents, excessive noise, or disruptions to traditional sporting experiences. Coaches may also be reluctant to adopt drone-based performance analysis because they are unfamiliar with the technology or question its reliability. Spectators may object to drones flying overhead during crowded events. Building public trust requires transparent communication, safety demonstrations, appropriate privacy safeguards, and evidence that drone technology provides meaningful benefits.
- *Overdependence*: Another challenge is the possibility of excessive dependence on drone technology. Coaches and sports analysts may begin to rely heavily on aerial recordings and automated performance assessments while giving less attention to direct observation, personal experience, and communication with athletes. Technical failures could then disrupt training programs or decision-making processes. Furthermore, data-driven assessments may not fully capture psychological factors, teamwork, motivation, and other human elements that influence athletic performance. Drone technology should therefore complement rather than replace human expertise.

FUTURE OF DRONES IN SPORTS

The future of drones in sports is promising, with opportunities to transform broadcasting, athlete training, performance analysis, officiating, event security, and spectator engagement. It will be influenced by advancements in artificial intelligence, autonomous navigation, computer vision, wireless communication, and battery technology. AI-powered drones will increasingly be capable of tracking athletes, recognizing sporting activities, identifying important moments, and adjusting their movements without constant human control. Future drone systems could incorporate AI-based image recognition to identify relevant incidents and automatically highlight situations requiring review.

The development of intelligent autonomous drones is expected to reduce the need for manual operation, improve filming consistency, and make aerial monitoring more efficient. However, their adoption will depend on reliable safety systems and compliance with aviation regulations. Future drones are expected to feature higher-resolution cameras, advanced image stabilization, intelligent tracking systems, and improved real-time video transmission. These capabilities could allow broadcasters to capture sporting events with greater precision and creativity. In the future, coaches may use drone-generated information to develop individualized training programs, identify technical weaknesses, and monitor improvements over time. Such applications could make sports training more scientific, precise, and effective [1].

CONCLUSION

Drones have emerged as one of the most innovative technologies transforming the sports industry. They have considerable potential to transform the sports industry by improving broadcasting, athletic training, performance analysis, event management, and spectator engagement. However, their successful adoption requires attention to safety, privacy, regulatory compliance, operational costs, and technical limitations. As artificial intelligence, sensor technology, and autonomous systems continue to advance, drones are likely to play an increasingly significant role in the development of modern sports. Their integration into sporting activities represents an important example of how emerging technologies can transform athletic performance, sports management, and the spectator experience.

As drone technology continues to advance, its contribution to sports is likely to become increasingly significant. With responsible implementation and continued innovation, drones can help make sports safer, more efficient, more competitive, and more entertaining. They represent an important technological development that is reshaping how sporting activities are practiced, analyzed, managed, and experienced.

Equally important is the development of ethical standards that protect privacy, promote competitive fairness, and preserve the integrity of sporting activities. Ultimately, the successful future of drones in sports will depend on balancing technological innovation with safety, responsibility, affordability, and human judgment. More information about the use of drones in sports can be found in the books in [14-16].

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Figure 1 A typical drone [2].



Figure 2 A drone is usually controlled by operators on the ground [3].

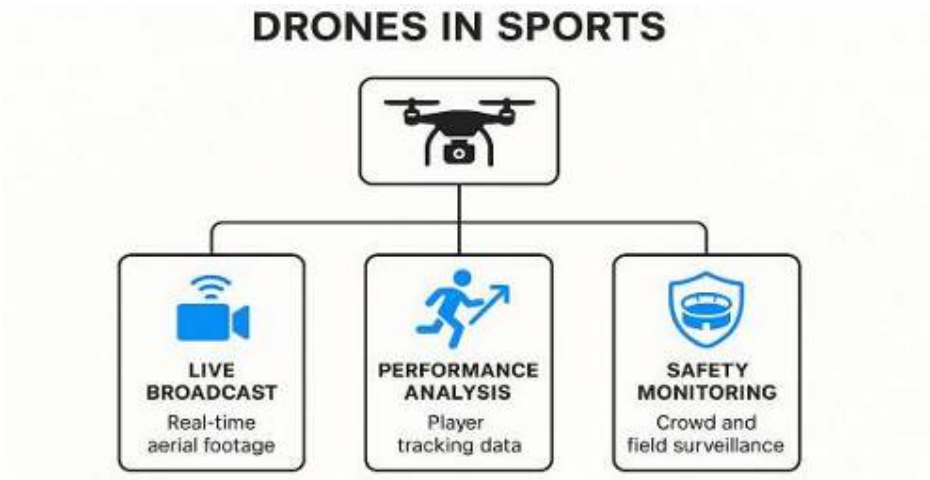


Figure 3 A representation of drones in sports [7].



Figure 4 A drone capturing sports events [10].



Figure 5 How drones are used for athlete training [2].



Figure 6 Football game drone [11].



Figure 7 Use of drones in sports broadcasting [9].



Figure 8 A drone for filming sports [12].