# ARSpectator: Exploring Augmented Reality for Sport Events

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**Figure 1: ARSpectator using the HoloLens and a mobile phone. Left) 3D structures of the stadium and line markings are overlaid using the AR interface on a Hololens. Right) Sport related information is overlaid using ARSpectator on a mobile phone.**

## ABSTRACT

Augmented Reality (AR) has gained a lot of interests recently and has been used for various applications. Most of these applications are however limited to small indoor environments. Despite the wide range of large scale application areas that could highly benefit from AR usage, until now there are rarely AR applications that target such environments. In this work we will discuss how AR can be used to enhance the experience of on-site spectators at live sport events. We will investigate the challenges that come with applying AR for such a large scale environment and will investigate state-of-the-art technology and its suitability for an on-site AR spectator experience. We will present a concept design and explore the options to implement AR applications inside large scale environments.

## CCS CONCEPTS

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

## KEYWORDS

Augmented reality, sport events, concept design

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## 1 INTRODUCTION AND BACKGROUND

Mixed and Augmented Reality (AR) techniques can extend our view of the physical environment by visually integrating digital information. While for decades AR was mainly driven by academic research, recently major investments from industry have increased the availability of AR tool-kits and frameworks. This allows developers with no prior AR expertise to develop AR applications. The reduction of entry requirements to AR development has contributed to many new AR applications that have previously only been described in research work. Examples includes AR applications for furniture shopping (e.g. IKEA Place), games combining virtual and digital elements (e.g. Pokemon Go or Lego), or even AR supported measuring tools. Most of the applications focus on small-scale environments, usually indoor locations. However, there are a lot of application areas that are not limited to an indoor or small scale environment that could highly benefit from AR.

**Augmented Reality and Live Sports** One application area for large scaled AR is live sports. If we look into popular sports that are broadcasted to millions, we see a drastic increase of information and statistics that are communicated to the viewer. Due to the increasing amount of information and complexity, traditional sports broadcasting has started using techniques from Mixed and Augmented Reality to visually integrate the information into the video footage [1]. Examples include visual overlays that show the names of players, pathways of individual players or groups, heat-maps showing ball possessions or activity on the field as well as the integration of cues highlighting important aspects of the game (such as offside lines in football). The common properties in these visualisations are that they are not in real-time, i.e. replays. Furthermore, enabling such visualisations, in particular those in 3D requires precisely registered cameras or sensors, which exists increasingly in modern stadiums.

[1]https://virtualeye.tv/

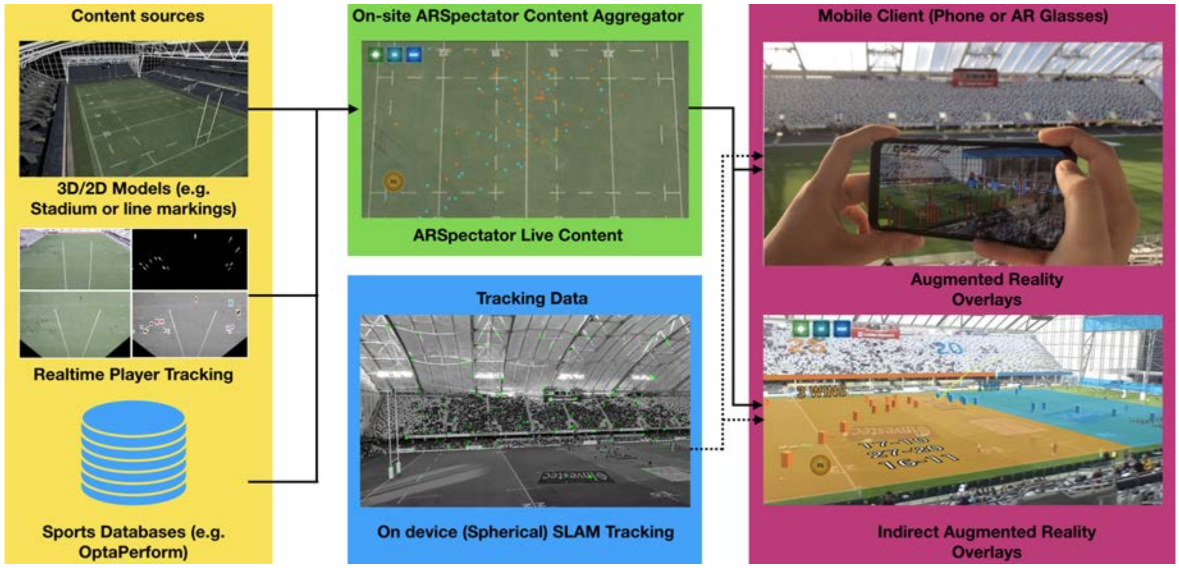


**Figure 2: ARSpectator overview. ARSpectator integrates sport-related data from different sources that are visualised via a direct AR or indirect AR interface.**

While these visual overlays are becoming the norm in sport broadcasting, live spectators attending sport events, e.g. in the stadium, still miss out. Considering the fact of future possibilities of sport broadcasting (e.g. free viewpoint selection or 3D broadcasting into VR headsets), this raises the question of why one should go into the stadium.

**Background** In recent years, a few companies demonstrated interest in using AR within large scale sport events. However, as of now there is no such system available. For instance, Apple[2] showed a demo for using AR within a Baseball game, but there is no further information about the feasibility and the technology used for this. In 2018, Panasonic demonstrated the vision of using AR in stadiums by using a large scale projection mapping. This simulated the actual stadium experience using AR technology[3]. Similar to the baseball AR application, it is not known when it would be actually commercialised and open to public.

Early works from academia in the area of AR for sports used 3D video capture with multiple cameras and integrated this into a pre-calibrated video stream[Koyama et al. 2003]. Similarly, Inamoto and Saito displayed 3D reconstructed soccer players on a table using an HMD[Inamoto and Saito 2003] focusing on the experience of remote spectators. Recent research investigated if AR interfaces would be beneficial to sport spectators by simulating an AR experience in stadium environment using a theatre setting [Rogers et al. 2017]. Another approach focusing on remote spectators at home was presented by Stropnik et al. by using a Hololens to display additional information next to a TV screen [Stropnik et al. 2018]. However, none of the studies looked into using mobile Augmented Reality at live sports events, leading to the challenges and opportunities in this field to be under explored.

[2] https://9to5mac.com/2017/09/25/mlb-at-bat-augmented-reality/
[3] https://na.panasonic.com/us/integrated-solutions/immersive-experiences

In this work, we present ARSpectator, and contribute a first prototype extending the experience for on-site spectators of sport events utilising an Augmented Reality interface. Besides providing a general overview on the components of ARSpectator, we also discuss the insights gained from building and using such a system.

## 2 ARSPECTATOR OVERVIEW

Using AR for delivering digital overlays in large-scale environments such as a stadium or sport field comes with additional challenges that are less of an issue in most traditional scenarios AR is used in. This is particularly evident in placing content in the right location and context of the user. It is important to know the location and orientation of the user with respect to the graphical content. In addition the content that is going to be displayed needs to be available in a spatial representation (for instance being captured as GPS positions with regards to the field).

In this work, we will present the overall concept of using AR for an on-site sport spectator experience as well as presenting the first prototypes and results from a feasibility study ran in a local stadium. The ARSpectator system consists of a mobile AR client and the ARSpectator content server (Figure 2). The ARSpectator client is used by on-site spectators to explorer game related content. The client is implemented as an android app as well as a Hololens app. It uses a combination of localisation and tracking in order to align the content to the view of the spectator.

The ARSpectator content server is also placed on-site and is connected to the tracking cameras and game related data sources (e.g. from commercial score providers such as Optaperform[4]). Content within the content server is represented in spatial relationship to a surveyed reference 3D model of the stadium environment and is delivered to the ARSpectator client.

[4] https://www.optasports.com

## 3 REGISTRATION

In order to accurately compute and place digital overlays in the spectator's field of view, we need to obtain information about the current spectator's view. In our case the spectator is envisioned to see the world by either using a mobile phone or AR glasses (e.g. MS Hololens) as an AR client. To track the view we must solve two challenges: 1) The localisation challenge in which we need to compute an accurate pose describing position and rotation of the the AR client within the physical stadium. 2) Once, this pose information is determined, we need to keep track of the movements of the AR client with respect to the stadium. We call this the tracking challenge. Solving both, localisation and tracking allows us to register digital overlays in the spectators view using the AR clients.

### 3.1 Localisation

We implemented and evaluated different localisation methods often used in industry and academia within a real stadium environment. All initialisation methods return the position and orientation of the AR client (mobile phone or AR glasses) with regards to our reference stadium model.

**User-guided Localisation** Initially, we experimented with user-guided localisation approaches. The intention was to have a fallback solution that should work independently of stadium environments and context at the costs of an increase in user efforts. Given the user's seat number, we roughly estimate the user's position. Using this estimate we provide an AR overlay of the sport field which can be refined by the user by aligning overlay and sport ground. This approach would require a spatial mapping of all seats in the stadium which is also not always easy (e.g. not always numbered seats). We also implemented a traditional perspective-n-point solution that requires the user to align given 3D marks and 2D points in the AR clients view to compute the pose of the spectator's device [Xiao-Shan Gao et al. 2003]. While both approaches work, we noticed that the usability is affected by the field of view of the AR client. Usually not all the corners of the sports field are visible, while other markings turned out to be often not reliable (badly visible or sometimes only roughly marked).

**Automatic Localisation** Sensor-based localisation (e.g. GPS) turned out to not deliver the accuracy required as the roof of the used stadium affects the satellite-based localisation. Thus we focused on vision-based localisation that is also known to deliver better accuracy. One promising approach is to use existing advertisements in the stadium (see Figure 3) and utilise it for localisation based on extracted SIFT features and known dimensions of the advertisements. During our feasibility tests within the stadium, we used the image target feature of Vuforia[5] which is commonly used for Natural-Feature based tracking. We achieved good results for the printed targets (see Figure 3, B and C) however, the performance with advertisements on the field (see Figure 3, D) is not very stable. In general, while achieving good performance and accuracy, this approach strongly depends on the advertisement and the position within the stadium and performance will be different if the used image target is far away or contains bad features according to SIFT or similar approaches.

[5]https://developer.vuforia.com

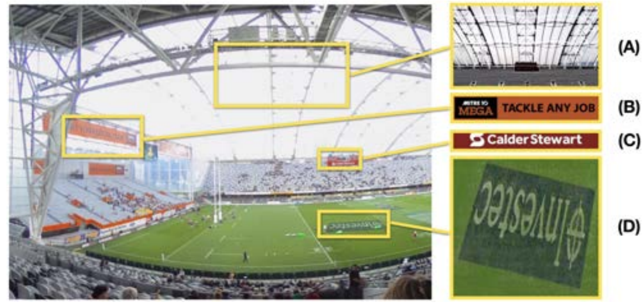


**Figure 3: Examples of different visual features tested and used for localisation. (A) 3D structures extracted from an existing CAD model of the stadium. (B,C) Static advertisement in the stadium (D) Advertisement on the field.**

In our case, we have a full CAD model of our test stadium environment (including roof) which lends itself for model-based registration methods but the availability is not always the case. We tested different implementations for model-based localisation (e.g. SoftPosit [Baker et al. 2018] and Vuforia's model-based tracking). However, results showed that this approach is very location dependent. As many parts of the stadium typically contain repetitive structure, this approach failed to deliver reliable results (see Figure 3, A).

### 3.2 Tracking

Once initialised, we rely on tracking for estimating our camera pose. In recent years, SLAM approaches have shown promising results also in larger scale environments [Mur-Artal and Tardos 2017]. Also our initial tests showed that SLAM/Visual Inertia Odometry approaches as integrated in ARKit/ARCore are working reliably enough for initial prototypes and to test the feasibility. However, the specific movement patterns for sports spectators (static position with mainly rotational movements) and location (large open environments with only minimal parallax) are against some assumptions traditionally made for SLAM trackers. When considering these information in the SLAM implementation by using a spherical constrain, we can improve the performance of traditional SLAM trackers within stadium environments (see Figure 4 showing successfully tracked frames during a live game (rugby 1 and 2) and within an empty stadium (stadium)).

## 4 VISUALISATIONS

For creating the visual overlay we are tapping into different data sources but all data is combined in our own content aggregator server (see Figure 2). Existing data sources include existing 2D and 3D models (e.g. stadium models or static line overlays), information from our own player tracking that allows to show player paths or names among other information (computed from one or several stadium-installed wide angle camera views using background separation and optical flow techniques). Finally, we also integrate information from commercial sport databases (e.g. OptaPerform).

We combine these overlays into different visual overlays and identified the following categories: *Player-based visualisations* for

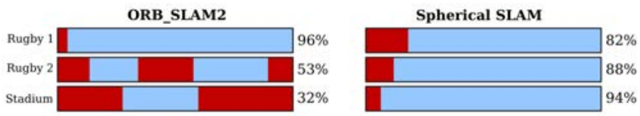


**Figure 4: Comparison of traditional SLAM approaches (here ORB SLAM2) compared against our Spherical SLAM. Blue represents a successfully tracked frame, red represents an untracked frame.**

example player names, physiological data, game related data, *team-based visualisations* such as ball possessions or field events, *game-based visualisation* including showing games rules or hints such as offside that are not team or player specific. Finally, we see our approach can also be of use for *crowd-based visualisations* such as interactive games or entertainments for the crowd during breaks or even for emergency situations (e.g. evacuations) and implemented first prototypes for this.

One particular challenge we face is that some information traditionally delivered for TV broadcasting comes in close to real-time (e.g. with a latency of seconds) but for AR we need real-time overlays. To compensate this, we also integrated an indirect AR interface [Wither et al. 2011] for sports. In contrast to direct AR where the overlay is shown on top of the live camera feed of the device, within the indirect AR interface, we overlay the digital information on top of either a panoramic image, panoramic video, or a rendering of the scene. The advantage of this scenario is that one is able to replay a scene (thus relaxing the latency issue for some of the content) as we are not relying on the live camera feed while still keeping the immersiveness of the AR interface as the device is still fully tracked and responding to the users movements.

## 5 CHALLENGES AND OUTLOOK

We identified several challenges during our ongoing work on integrating Augmented Reality into live sport events. In this section we will highlight some of the major ones:

**Latency:** In traditional sports broadcasting, most visual overlays are not computed in real-time but computed for replays of certain scenes. This allows latency in parts of the pipeline and make it less critical, as longs as correct timestamps are used. However, for real-time AR overlays, latency is a significant factor to consider. Depending on the infrastructure (e.g. cameras in the stadium or content-database) we experienced practical latency above 500ms. Choosing Indirect AR as an interface allows us to circumvent the latency issue but is only useful for replays of certain scenes.

**Localisation:** We have presented several approaches for initialising the tracking. However, we acknowledge that none of the approaches is guaranteed to work in all stadium environments as the performance still strongly depends on the availability of certain 2D features (e.g. advertisement) or 3D features (e.g. stadium geometry) in the stadium. Consequently, we think there is still space for finding a robust and generic approach that can be used in different stadium environments.

**Visualisation:** More research would be needed to determine what kind of visualisation is appropriate for AR applications. Traditional broadcast visualisation that often focus on only one perspective needs to be mapped to a 3D coordinate in order to make sense to all perspective. It is also important to minimise the distractions caused from the visualisations. Proper user experience design would need to be conducted to ensure visualisations that are useful yet unobtrusive to the users. Similarly, we have yet to find out the preference with respect to the AR and indirect AR user interface.

**Usability:** Finally, while this work presented first prototypes for enhancing live sport events with AR, we have not receive user feedback from real users and we need feedback from empirical studies to see how our approach enhances or maybe even disrupts the sport experience which is something we are working on at the moment.

In summary, this work presents a first approach for utilising AR to enhance live sport events. We presented an overview on our initial AR prototypes with a focus on the registration and visualisation challenges experiences throughout the project. In the future, we want to pursue remaining challenges in tracking using model-based tracking with 3D models of the stadium environment as the potential of using static 3D geometry for registering the AR view is obvious. A second research direction of ours is to further investigate visualisation techniques. While we proposed some examples in this work, future work aims to receive feedback from empirical studies and more structurally explore the possibilities and demands of actual spectators.

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