Smart Stadia as Testbeds for Smart Cities: Enriching Fan Experiences and Improving Accessibility

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***Abstract*—Rapid urbanization is introducing a variety of challenges for municipalities. Technologically-enabled 'Smart Cities' are rising to meet these needs, which include smarter sustainability, cybersecurity, transportation, waste management, energy efficiency, education, among many other areas, all toward enhancing the quality of life of citizens. These cities leverage the capabilities of Internet of Things (IoT) technology and the service economy to infuse sensing and information delivery into everyday life through the power of data analytics and artificial intelligence. However, the size of a city and its population make it difficult to evaluate smart solutions. In this work, the 'Smart Stadium' is proposed as a testbed to trial Smart City technologies in an environment small enough to facilitate user trials yet large enough to produce scalable outcomes. Our previous proof-of-concepts are summarized to highlight the potential of this approach. We also present a more recent project on accessibility and inclusion using virtual reality with preliminary results.**

Keywords— smart stadium, smart campus, smart cities, Internet of Things (IoT), virtual reality, multimodal interfaces, haptics

I. INTRODUCTION

The increasing ubiquity of sensors, wireless connectivity, artificial intelligence, and information delivery technology have opened new possibilities for the interaction between people and their environments. These "smart environments" have formed testbeds for Internet of Things (IoT) technology with increasingly large populations, toward improving security, social interaction, accessibility, among other areas. At a much larger scale, Smart Cities aim to tackle challenges arising from the rapid surge of urbanization worldwide, which is expected to reach roughly 68% of the world's population by 2050 [1]. These challenges relate to automation, sustainability, cybersecurity, transportation, energy optimization, waste reduction & management, health & healthcare, citizen engagement, and education. Smart cities initiatives intend to assist with many of the challenges that this urban growth brings while also providing the many benefits present in the service economy [2, 3].

However, the sheer magnitude and scale of a city presents difficulty in the evaluation of new tools, services, and technologies. In this case, it is necessary to focus the scope of this challenge at a level that allows for a manageable test population while maintaining some of the scalability and challenges necessary for Smart City technologies. Therefore, in this work, we propose the utilization of an environment that meets these requirements in an active population: the sports stadium. The 'Smart Stadium' concept proposes that a sports stadium can be transformed into a dynamic testbed for IoT technologies, smart sensing, and information delivery and services in an environment that poses many of the same challenges presented by Smart Cities, yet at a smaller scale.

In 2015, as part of the Transatlantic Higher Education Partnership, Arizona State University (ASU) partnered with Dublin City University (DCU) to transform ASU's Sun Devil Stadium and Ireland's Croke Park Stadium into twinned Smart Stadia with sponsorship from Intel Corporation and the Gaelic Athletic Association (GAA). The geographic location of these two stadia provide a useful juxtaposition of weather conditions—in Arizona, we have too much sun, not enough rain; in Ireland, there is not enough sun, too much rain—in an effort to globally explore interesting research questions beneficial to the regions involved.

Through Intel's support, and leveraging large scale renovations at both stadia, the stadia were equipped with a multitude of sensors. At Sun Devil Stadium, 44 sensors boxes were built and installed throughout the

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south lower bowl (student seating area); each sensor box contains a microphone, vibration sensor, altitude sensor, and Bluetooth low energy (BLE). At Croke Park, a variety of sensors have been installed ranging from rain gauges to cameras.

With infrastructure in place, ASU and DCU have been developing, deploying, and evaluating Smart Stadium and City technologies and innovations over the last three years. Projects fall into one of two categories: (i) Enriching the fan experience; and (ii) Improving the stadium environment. In Section II, we highlight past projects within the aforementioned areas, demonstrating the potential for Smart Stadia to function as testbeds for Smart Cities. In Section III, we present a new project on using virtual reality for access and inclusion. Finally, Section IV outlines future directions for research.

II. Smart Stadium Proof-of-Concepts

ASU's smart stadium projects have focused on enriching the fan experience. These projects include:

- ***Wait time and queue estimation***: This project aimed to provide a platform for fans to access wait times at concession stands and restrooms in real-time from a smartphone application. Our vision-based approach applied density estimation techniques within an active learning framework to reduce labeling burden [4]. The proposed framework may be applied to CCTV cameras found around the stadium concourse. More broadly, our proposed methodology could be utilized by Smart Cities to provide citizens with access to wait times and crowd densities at various locations and events.
- ***Victory cheer***: To enhance fan participation and camaraderie, we designed and deployed during a live game a *game-within-a-game* experience called Victory Cheer [5], played during intermission. Microphones within sensor boxes detected noise levels of cheering sections across the stadium. As sections cheered and competed, the Jumbotron depicted in real-time the noise levels across sections. The deployment of Victory Cheer was successful, and is opening new vistas of research into how serious games can be used for citizen engagement and participation at a Smart Campus and City scale.
- ***Athletic Demonstration Platform***: One way to connect fans with a sport and motivate physical activity for health and wellness is through demonstration and instructive evaluation of sports motions. Real-time motion sensing and body tracking technology yields the ability to automatically assess and provide feedback on a user's performance at a particular motion-task to promote unsupervised training in sport. Challenges posed by such a system include reliable real-time motion and body-capture, accurate and user-flexible means of providing real-time assessment of motions, and user-friendly communication of sports-motion data, both in demonstrating the correct motion and in communicating the performance at that motion. Such a platform should clearly be able to distinguish and communicate the difference, for example, between a novice football-throw, and that of a professional athlete, and to help guide the user toward improvement of his or her throw. To accomplish this objective, together with DCU, we jointly developed the Athletic Demonstration Platform to create a proof of concept of an automated sports-motion evaluation and demonstrative guidance system which includes expert motion data for demonstration and assessment as well as real-time motion sensing and multimodal feedback. The motion capture technology is low cost yet accurate, fusing inertial and vision-based sensing—refer to [6] for further details.

DCU's smart stadium projects have focused both on enriching the fan experience and improving the stadium environment. Here, we highlight one on-going project of DCU's on crowd behavior analytics toward improving stadium security and safety.

- ***Crowd Understanding***: Stadia are designed to support large gatherings of people, but any large gathering can pose a risk to safety. Therefore, enhancing safety at stadia and other venues within Smart Cities designed for large gatherings, especially given the rapid rates of urbanization, is of utmost importance. Noel O'Connor and his research team at DCU have led Smart Stadium projects at Croke Park on crowd behavior analytics toward understanding crowds—both their behaviors and densities—to improve the security of the stadium and the safety of attendees. They have explored both vision-based and non-vision-based algorithms for crowd behavior analytics including density estimation techniques. Previously [4], they presented an efficient strategy to estimate low dimensional and informative features that describe holistic information about objects moving within a scene toward crowd understanding and differentiating between normal and abnormal crowd behavior.

Our past projects highlight how smart stadia may be leveraged to ideate, develop, deploy, and evaluate Smart City concepts, technologies, and solutions within a small but scalable environment. In the next section, we highlight a more recent Smart Stadium project using virtual reality to enhance accessibility and inclusion in sports.

III. Virtual Reality for Augmented Stadium Attendance

A. Overview

For today's sports fan, a live sport event offers more than just a view of the game; it is a physically immersive experience, uniting fans and communities by the thousands as they support their favorite team and players. A seat at the stadium offers the energetic atmosphere where, in addition to watching the game, attendees can hear the roar of the crowd and feel the rumble of the stadium, engaging in a more memorable, multi-sensory experience compared to watching the game's broadcast from home. Currently, fans must physically attend a game to receive the "stadium experience," and this attendance is limited by the stadium's location, the number of seats available, and the view of the game from a single seat. Fans watching from home are further limited by the camera view offered during the live broadcast. These factors all place limitations on a fan's control over his or her sport experience.

With the rising ubiquity and lowering costs of commodity VR technologies, interest is shifting to new applications such as immersive 360 video experiences. Most solutions currently utilize VR camera rigs (e.g., GoPro Omni) that require complex and expensive processing pipelines to generate high-quality VR content for 360 video. More recently, promising progress has been made toward converting traditional broadcast video feeds to VR content that is comparable in terms of immersion, presence and quality afforded by VR camera rigs [7]. It is therefore timely to explore how stadiums may support VR experiences to allow fans to attend and enjoy games remotely. This project aims to extend the stadium experience to audiences who cannot as a result of distance, seating limitations, or limited accessibility, physically attend and enjoy a live sport event.

The globalization of sport has historically proven a significant factor in the cultural, social and economic relations between societies. The Olympics, for example, have been the bastion of these efforts, providing a global stage upon which the diverse nations of the world can cooperate, compete, and unite on a massive scale [8]. Globalization has allowed sports which originate in continents to expand on an intercontinental scale until they form worldwide audiences and participants, and in so doing, share the experience of participation of these events across cultural boundaries [9]. The primary medium for this globalization, to date, has been the live broadcasting of sport events through television, online streaming, or audio broadcasts [10]. However, improving the immersive qualities of the medium can enhance the audience's sense of presence and engagement with a sport event [11]. The National Basketball Association (NBA), for example, has already begun to offer VR services as an alternative broadcasting platform for viewers [12]. However, the physical elements of the viewing experience (such as the rumble of the stadium) are not present, and the viewer has limited control over perspective of the event during live coverage.

This work intends to address the aforementioned limitations and demonstrate the potential of VR and Smart Stadium technology in globalizing the full experience of live attendance. One point of exploration is how multimodal data can most efficiently and accurately be used to represent a sport event virtually, and how this representation can be made accessible to a wide variety of fans. In particular, the project aims to enhance access and inclusion for those with disabilities including sensory, cognitive, and/or physical impairments. The proposed technology will provide a platform for researchers to explore questions from social impacts to participation across demographics including enhanced accessibility for individuals with disabilities.

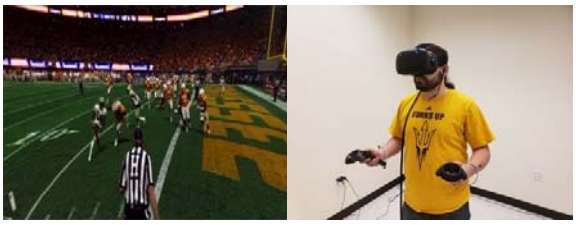

Figure 1. Multimodal Virtual Reality Platform. Left: User's current view of the game. Right: User wearing the HTC Vive VR equipment.

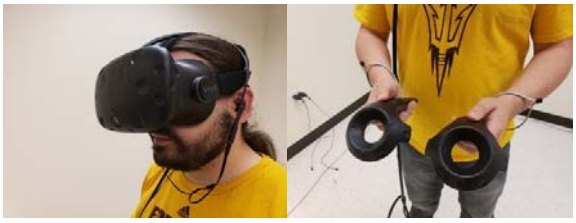

Figure 2. Close-up of HTC Vive equipment. Left: Headset and earbuds. Right: Vive controllers with vibrotactile feedback capabilities to simulate feeling the rumble of the crowd.

A proof-of-concept demonstration platform was built (Fig. 1) to provide an immersive, multimodal (360 video, audio, and touch) VR experience for sport events. The HTC Vive (Fig. 2) was used for the VR equipment and setup. The platform was implemented in Unity using SteamVR SDK, with a 360 video file projected as a skybox into the virtually-rendered scene and the basic

Vive interface enabled with two projected Vive controllers. Audio feedback was implemented using an audiosource object. Currently, there is one such object outputting the audio from the video, but multiple audio sources can be added so that additional effects, like a sound from the left or right of the user, can be emitted. Haptic feedback may be provided at specific predefined times within a prerecorded video, or alternatively, may be triggered based on a pre-defined threshold applied to a channel supplying data related to haptic activity, e.g., a vibration sensor within the stadium.

B. Evaluation

At this preliminary phase, the objective was to conduct a survey with those who have attended games at the ASU Sun Devil Stadium (or watched ASU games at home) to determine what features constitute the optimal experience for watching a Sun Devil Stadium sports game in Virtual Reality (VR). By determining what features provide the optimal viewing experience for sports fans, we can explore a connection between the rich multi-modal data provided by the many sensors, cameras, and other technology in ASU's Sun Devil stadium during a sports game, and the delivery of this real-time data in a virtual environment as an alternative medium for future sports experiences. The target audience for this need-finding study was individuals who have attended an ASU Sun Devil game and/or watched an ASU Sun Devil game at home. Individuals with disabilities were open to participate in the need-finding study as well to help determine the challenges faced by these individuals when attending a game in-person or when watching a game at home.

Participants were asked to complete the survey consisting of a series of free response questions and Likert scale questions as follows:

1. What challenges, frustrations, and/or shortcomings do you experience when you attend an ASU sports game in-person? Briefly explain.
2. What challenges, frustrations, and/or shortcomings do you experience when you watch an ASU sports game at home? Briefly explain.
3. What are your favorite reasons for attending an ASU sports game in-person? Briefly explain.
4. What are your favorite reasons for watching an ASU sports game at home? Briefly explain.
5. Imagine and describe the experience of attending a sports game as a fan/audience member in the year 2036. What might have changed since today? Briefly explain.
6. We are working on a project exploring the use of Virtual Reality to allow a fan to attend an ASU sports game remotely. Imagine being able to see and hear the sights and sounds on game day, watch the game from any angle, and feel the rumble of the crowd when the Sun Devils make a touchdown.
   - Would such an experience be of interest to you? Rate on a scale from 1 (low) to 5 (high).
   - Do you have any concerns using Virtual Reality? Briefly explain.
   - Do you think you'd likely attend more games if you could attend virtually? Rate on a scale from 1 (low) to 5 (high).
   - What features or options would you like to include in such a technology to overcome the aforementioned challenges, frustrations, and/or shortcomings you mentioned earlier related to attending a game in-person? Briefly explain.
   - What features or options would you like to include in such a technology to overcome the aforementioned challenges, frustrations, and/or shortcomings you mentioned earlier related to watching a game at home? Briefly explain.

C. Results and Discussion

Seven participants completed the survey for this preliminary phase. For question #1, the most common frustration expressed by attendees in stadiums is traffic, crowd congestion, and difficulties with seating, especially when seats are not assigned. Furthermore, some participants indicated that it was often difficult to view the event from their seat. For individuals who are blind, it was expressed that the experience requires attendance with a sighted individual who relays information about the event and surroundings due to inaccessible visual information. The primary frustration expressed in question #2 is that, when watching a sports game at home, the experience lacks the intensity, energy, immersive cheering, and participation of the crowd in a stadium, as well as stadium-based experiences such as the marching band's performance.

Reasons given for attending games in-person in question #3 included the atmosphere as stated above as well as the opportunity to socialize with friends and meet fellow students. Reasons in question #4 included the convenience of avoiding traffic, control over visuals and sound, and easy access to food and restrooms during an event. One response noted that while games were more accessible at home, the experience of the stadium atmosphere was generally a more important factor for enjoyment.

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A variety of insights were given as possibilities for a sports experience in the year 2036 as introduced in question #5. Some common themes included instant access to replays in real-time through phones or other technology; the ability to view a game in real-time from any point-of-view at any position in a stadium; the ability to view the game from a player's perspective/point-of-view; greater access to information and statistics about the game as it occurs in real-time; interaction with a variety of IoT devices to enhance the experience; and augmented reality elements including holographic displays and laser projections.

Based on the results from question #6, there was strong support for a virtual reality-based stadium experience from fans. Participants indicated high interest in the experience (average score of 4.43, standard deviation of 0.787) and high likelihood of attending more games if it was possible to attend virtually (average score of 4.14, standard deviation of 0.900). The only concerns expressed about virtual reality were that prolonged usage of the technology could cause dizziness and nausea, that the display fidelity of VR headsets is limited, and that making the technology widely accessible to sports fans would pose a challenge. Features of interest included the ability to emulate the vibrant atmosphere of the stadium experience, the ability to freely control the viewing perspective within the virtual experience, accessibility of information and services (such as ordering food) within the virtual environment, and the addition of social features so that the viewer may interact with other viewers within the virtual space as he or she would interact with friends or other fans in the live event. Overall, these results show promise for the potential of this technology to augment the stadium experience. Many of the insights offered by survey responses are being taken into account for prototype development. Beyond sports experiences, we are interested in exploring how virtual attendance and experiences can enrich other aspects of citizens' lives including citizen awareness, engagement, and education.

IV. Conclusion and Future Work

In this work, proof of concepts were presented to demonstrate how smart stadia may be used as testbeds for trialing Smart City ideas and innovations, at a scale that is small enough to provide a useful deployment platform, yet incorporate the challenges of a city environment. Based on survey feedback, the proposed VR platform will be fully developed and evaluated as part of future work. In performing this evaluation, the advantages and limitations of applying this approach at the scale of a stadium can be explored, followed by strategies for scaling for other venues within Smart Cities. Furthermore, patterns can be drawn between the solutions presented here and the challenges presented at the level of a Smart City. For example, the concept of accessible, remote attendance in Virtual Reality can be applied to a variety of everyday needs for individuals with mobility impairment living in urban, crowded areas. While there is much to explore within this context, these projects together demonstrate the potential for smart stadia as a platform toward the future of digitally-enabled urbanization.

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