A Framework for Location-Based VR Applications

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Abstract: This paper presents a framework to develop and investigate location-based Virtual Reality (VR) applications. We demonstrate our framework by introducing a novel type of VR museum, designed to support a large number of simultaneous co-located users. These visitors are walking in a hangar-scale tracking zone (600 m^2), while sharing a ten times bigger virtual space (7000 m^2). Co-located VR applications like this one are opening novel VR perspectives. However, sharing a limitless virtual world using a large, but limited, tracking space is also raising numerous challenges: from financial considerations and technical implementation to interactions and evaluations (e.g., user's representation, navigation, health & safety, monitoring). How to design, develop and evaluate such a VR system is still an open question. Here, we describe a fully implemented framework with its specific features and performance optimizations. We also illustrate our framework's viability with a first VR application and discuss its potential benefits for education and future evaluation.

Keywords: Virtual Reality, Framework, Hangar-Scale Tracking, Multi-users, Museum

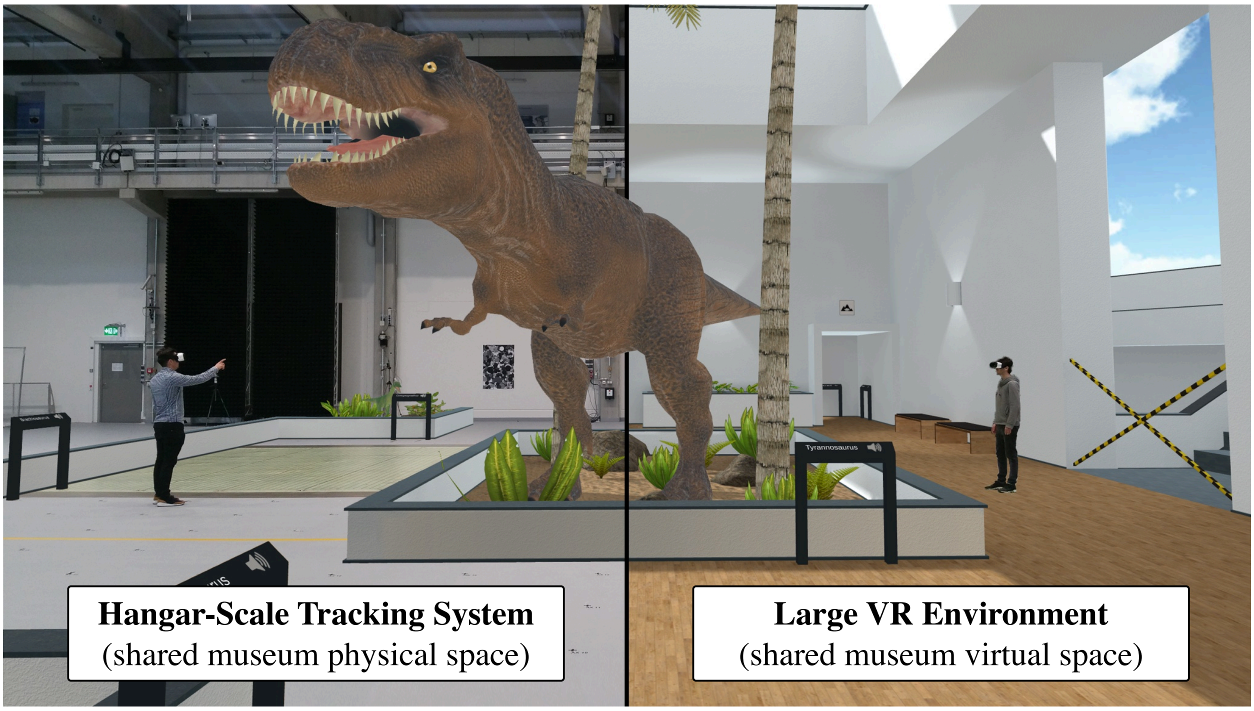

Figure 1: Location-based VR Museum Overview

1 Introduction

Digital technology has changed the way museums document, preserve and present cultural heritage [SFKP09]. Museums are frequently modernizing their exhibitions with digital experiences, for instance with Virtual Reality or Augmented Reality (AR) applications [WBL+04]. Digital games in museums are one efficient approach to socially involve large groups of students in learning complex material collaboratively [ABC18].

With the recent advent of VR Theme parks (e.g., *The VOID* [THE16], *VR Park Tokyo* [ADO18]), one could imagine that the next generation of museums will be a *fully* virtual one: i.e., a location-based VR Museum, which is purely based on a virtual world exhibited in a large single physical space shared by many users (Figure 1). This type of co-located VR system represents an exciting and novel application of VR, especially for social-based activities such as education, entertainment, culture and art. VR Systems like, e.g., RB2 [BBH+90], the MR Toolkit [SGLS93], SIMNET [CDG+93], VR-DECK [CJKL93], MASSIVE [GB95] to MASSIVE3 [GPS00], DIVE [FS98], or AVANGO (formerly AVOCADO) [Tra99] paved the way for today's multiuser VR systems. However, the architectures of location-based VR systems have been hardly described, and their potential affordances rarely demonstrated. In this paper, we are presenting in details the framework we developed for a co-located VR Museum called *Holopark*[LKS+18]. We also discuss its uses as an experimental platform to study their benefits, limitations and challenges with a VR museum use case.

Figure 2: Museum's Virtual Zones Overview - A) Three-Floor Museum Building, B) Third Floor, C) Second Floor, D) First Floor, E) Floor Grounded Enclosure, F) Glass Platform, G) Wooden Bridge, and H) Hangar-Scale Tracking Area (32m x 20m).

2 Potential Affordances

In a traditional VR museum, relying on a distributed VR environment, each user is in a different physical place (e.g., at home) but sharing the same virtual world (usually synchronized through network connections). In a location-based VR museum, all the visitors are walking and sharing the same physical space while also sharing the same virtual world (Figure 1). This users physical co-location is a unique and critical property. It could preserve the important social aspect of the "real" museum experience, involving *visiting* exhibitions in groups

1	Solve issues of space limitation for new exhibitions [SFKP09].
2	Reduce the exhibition's cost and installation time [SFKP09].
3	Solve concerns regarding the fragility of museum artifacts [SFKP09].
4	Foster social engagement and collaboration with multi-user interactive exhibitions [ABC18].
5	Enable experiences and interactions with extinct destroyed cities or historical sites.
6	Produce a new customized museum experience modulating the content presentation based on ages cultures and preferences (e.g. a better view for kids or persons with impairments or disabilities).
8	Provide a platform for new types of exhibitions (e.g.engaging one or many visitors in interactive storytelling exhibit)
9	Preserve the important social aspects of a museum (e.g.visiting and learning in groups of friends & colleagues or students).

Table 1: VR Museum Affordances

or with family and friends. This could potentially increase visitors' enjoyment, engagement and learning outcomes compared to more traditional VR museum (see in table 1).

However, due to the lack of hangar-scale tracking systems, the feasibility as well as the potential benefits or limitations (e.g., health and safety issues, user acceptance or learning outcomes) have never been demonstrated yet. Consequently, our first research step focused on designing and programming a VR framework, which can meet the requirements of such a VR museum. Our first prototype implements a VR prehistoric dinosaur museum, that was used for first informal evaluations and as a foundation for further developments.

3 Virtual Museum Environment

As depicted in figure 2, the virtual environment consists of a museum and a dinosaur park with six virtual zones in total (3 Inside and 3 Outside). The indoor museum consists of 3 floors with 1800 m^2 (Figure 2-A,B,C,D) and 11 exhibitions. The outside part is a park of 5000 m^2 including 3 exhibitions showing live dinosaurs (Figure 2-E,F,G).

Inside the museum, 10 exhibitions offering audio based descriptions, which include information about the type of the dinosaur and their habits (Figure 5). Some exhibitions also allow the visitors to trigger animations displaying the dinosaur's skeleton or natural look. The three outside exhibitions provide different perspectives on the environment and should enable the visitors to get close to the dinosaurs, inspect their different behavior and movement techniques, and getting a relative impression about the prehistoric sizes of nature and dinosaurs. The floor grounded enclosure (Figure 2-E) enables the visitors to observe the dinosaurs from a ground perspective, while the museum terrace and its glass floor allows a view of the dinosaurs and environment from above (Figure 2-F). The third outdoor exhibition consists of a wooden bridge in the mountains where visitors can observe flying dinosaurs

(Figure 2-G).

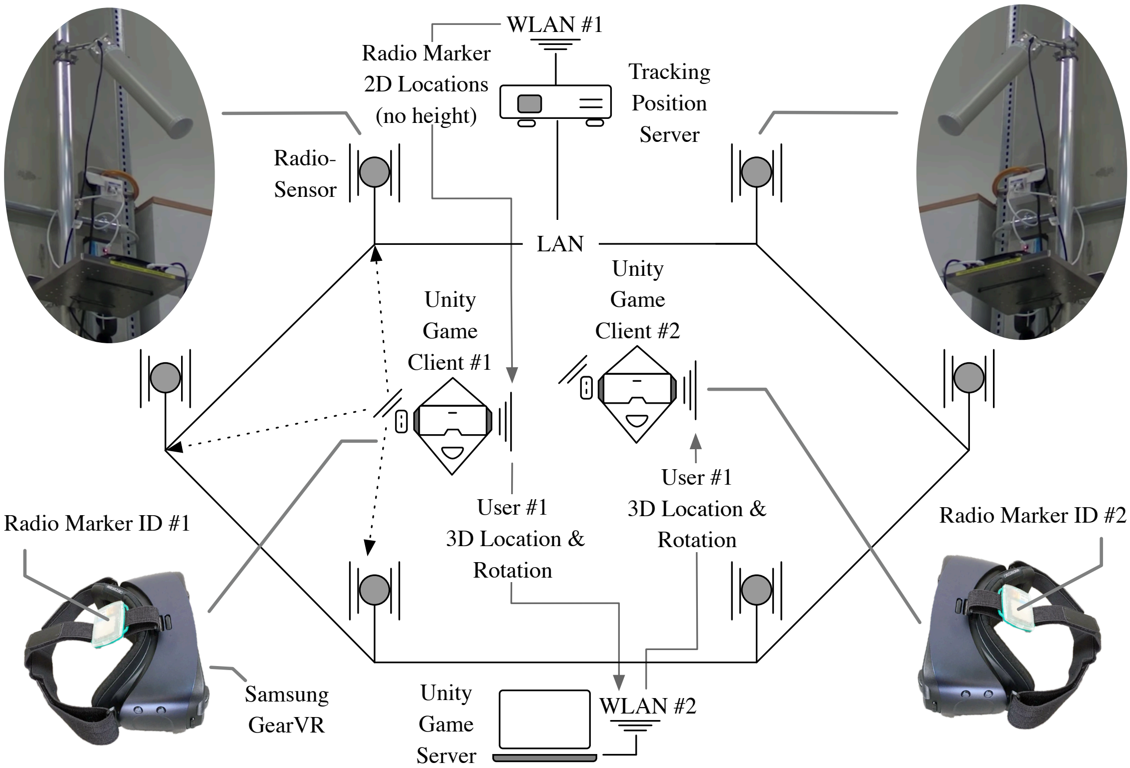

Figure 3: User Tracking and Replication System Overview.

4 Framework

The figure 3 illustrates the overall system architecture (hardware and software). The VR headset used is the Samsung GearVR HMD in combination with a Samsung Galaxy S7 or S8 smartphone. Audio information is provided by a *Beyerdynamic DT-1* one-ear headphone. The system is implemented using a specific client/server framework built on the top of the Unity Game Engine 2017.1 which is composed of the following components (Figure 4):

User Tracking and Replication System: The tracking system, illustrated in Figure 2-H, is providing a hangar-scale position tracking zone of 600 m^2 (with a theoretical maximum of 1400 m^2). The system is called *Holodeck 4.0* and installed at the Fraunhofer Institute for Integrated Circuits IIS in Nuremberg in Germany. It consists of several radio stations, which are connected to a tracking server, and radio marker IDs attached to each Samsung GearVR HMD (Figure 3). The system is a large-scale radio frequency-based real-time location system (RTLS), operating in the Gigahertz band [vdGFW+11]. The tracking server constantly computes and broadcasts the radio marker IDs' 2D locations (no height tracking) over a second wireless network. Unity game clients receive and parse their own 2D location in the hangar. The head rotations are provided by the headset inertial measurement unit (IMU). Each Unity game client derives then its own 3D location and rotation in the virtual world and sends it to the game server to be replicated on other clients.

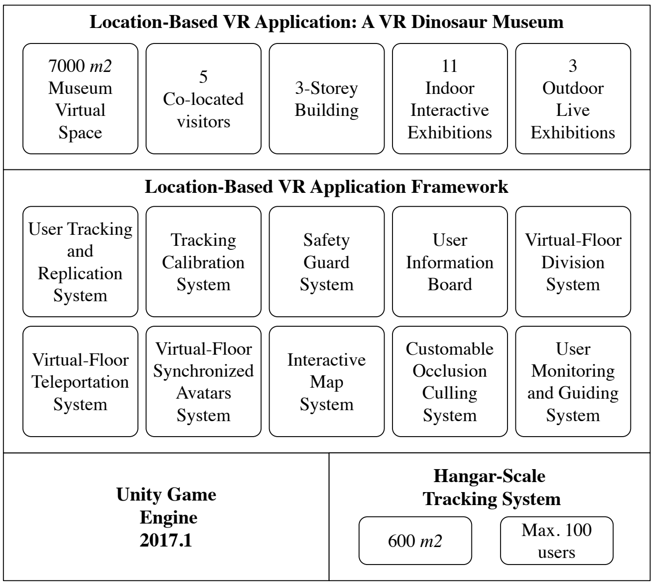

Figure 4: Framework Components Overview.

Figure 5: An indoor exhibition including an information board, which the user could interact with by gaze-based activation (Red circle with center point). The audio commentaries are synchronized among all visitors around the information board (same visitors group).

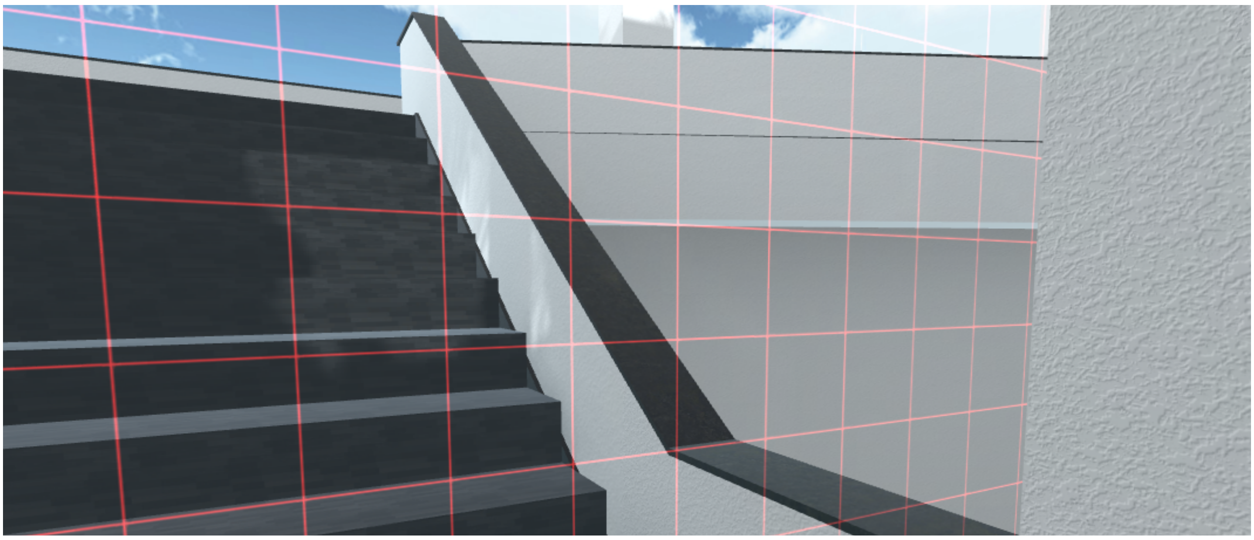

Figure 6: The safety guard system shows a grid when reaching tracking limits or prohibited areas.

Tracking Calibration System: Tools and procedure to initialize and align user head rotation and position in the virtual world.

User Information Board System: Visitors can activate 3D panel for visual and audio descriptions by looking at them for few seconds (gaze-based activation) (Figure 5).

Safety Guard System: Tool to rapidly specify the tracking system limitations and warn the user in critical areas (Figure 6).

Virtual-Floor Division System: The overall virtual environment is divided in smaller section called: *virtual-floor*, whose dimensions correspond to the tracking floor's dimension. As explained below, these virtual zones are used to simulate an *unlimited* virtual world within a limited tracking system, by supporting additional floors and navigation between them.

Figure 7: The *User Monitoring and Guiding System* - with multiple camera selections (including visitor's perspective) and the *Virtual-Floor Synchronized Avatars Representation* - Opaque: same virtual zone, transparent: different virtual zone (e.g., visiting an exhibition on a different floor).

Virtual-Floor Teleportation System: Visitors can access exhibitions on different floors or outside through a *teleportation* procedure [WKFK18] using an *elevator-metaphor*, also activated via gaze-based activation. The path and position of the central building elevator is indicated by indoor and outdoor wall signs in the virtual environment. A simple fade in/out black transition was used to simulate the opening and closing doors of an elevator.

Virtual-Floor Synchronized Avatars System: Visitors can see their virtual body (i.e., simple blue pillar) as well as seeing other visitors' avatars (Figure 7). We use a similar technique to the *shadow-avatar* [LHS18] to prevent visitors collision. A visitor with a transparent avatar (i.e., like a *ghost*) is indicating its physical proximity while being on a different virtual floor. This *anti-visitor-collision* system is an important safety feature for a large scale multi-user multi-virtual worlds parts. Naturally, visitors ignoring such avatar representation would lead to potential physical collisions and injuries.

Interactive Map System: Providing a *wayfinding* technique is important when navigating in large complex virtual world [LJKM+17]. Therefore, the visitor can see at any time an interactive mini-map of the museum on which they can see a *you-are-here* marker [BWHA98] as well as additional markers indicating other visitors positions in real-time.

User Monitoring and Guiding System: Museum staff, such as guides, managers or even technical supports can easily watch visitors and assist them via a special desktop game client acting as a virtual camera surveillance systems (Figure 7).

1	*Custom Occlusion Culling System* Every game object has a *Virtual Floor's ID* assigned, which are used to either enable or disable it when a user is entering or quitting the floor. For example, this reduces the triangle count on the third floor (Figure 2-B) from 76.6k to 44.3k and enables less than 65.0k triangles from all possible visitor museum perspectives (For an overall number of triangles of 198k).
2	*Optimizing quality settings* Optimizing the rendering quality settings for mobile VR usage (see *Oculus* [Ocu15] and *Unity* [Uni18]).
3	*Precomputed lights and shadows* Static meshes with pre-bake the light and shadows, and generating static lightmaps.
4	*Reducing triangles* Using less level of detail (LOD) of each mesh (Dinosaurs avg.: 5.5k (L0), 3.2k (L1) and 1.1k (L2)) and reducing the number of triangles with an externalapplication.
5	*Avoid complex shaders* Mobile optimized single-pass shader without reflections and only a few transparencies.
6	*Reduce the number of shaders and materials* Most of the meshes uses the same mobile shaders to enable Unity's Static and Dynamic Batching (i.e., 7 mobile shaders and 1 standard shader, used in 61 materials).
8	*Combine meshes* Objects were combined into one single mesh to reduce the number of draw calls.
9	*Script optimization* Identify and reducing bottleneck by profiling and optimizing complex computations.

Table 2: List of Performance Optimisations

5 Performance Optimization

In comparison to desktop computers, smartphones offer much less graphical and computational power. Therefore the application is highly performance optimized for virtual reality and follows the VR development guideline from *Oculus* [Ocu15] and *Unity* [Uni18], but also implements a customized occlusion culling system. The table 2 summarizes the most important optimizations techniques implemented.

Our performance optimization allowed a comfortable VR experience with 60 FPS on average. While the system provides an head orientations update at constantly 60 Hz, it only provides the position update at 20 Hz. Since the virtual world is rendered at a quasi-constant rate of 60 Hz, the frequency of the orientation update is sufficient [FMP18] [SNL16]. However, the low update frequency of the positions results in a varying motion-to-photon (MTP) delay [HLP+00] of an average of 246.34 ms [LBS+16]. A Kalman filtering algorithm [15] provides smooth positions with a probable circular error (i.e., horizontal accuracy) in 95% of <10.2 cm and a precision of <2.6 cm in both static and dynamic movement situations.

In order to collect some qualitative feedback, our first prototype was also tested with five simultaneous participants for 10 minutes (Figure 8). The feedbacks collected are promising, with many positive reactions, and an acceptable comfort level during the whole experience. The transparent avatar (Figure 7), indicating that a user is on a different virtual floor, was considered as helpful and easy to understand. The participants liked the separation between knowledge transfer and the live dinosaur park but would have liked to interact more with the dinosaurs. They also suggested a more unique and complete avatar representation, with heads and hands representation.

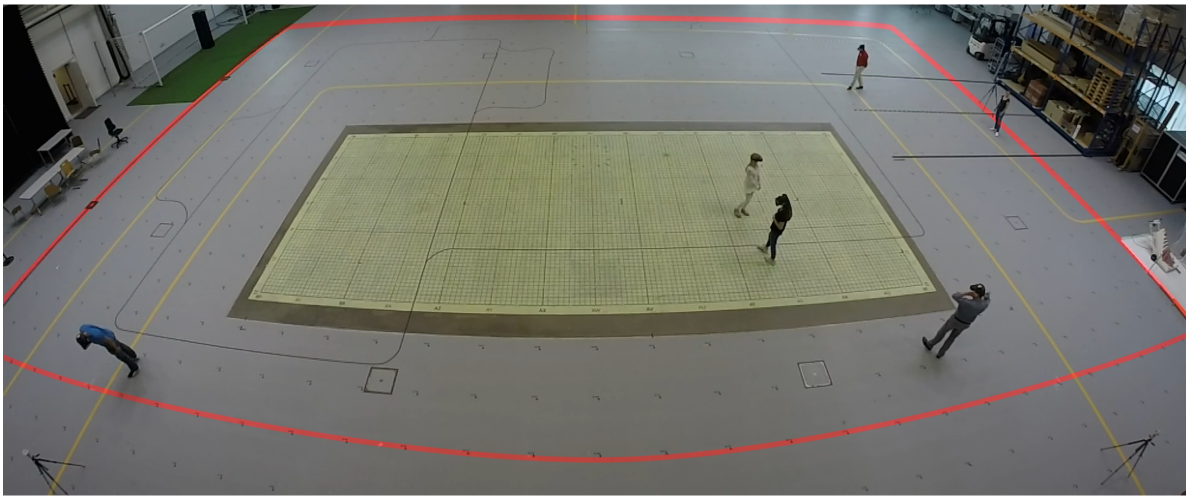

Figure 8: Example of five co-located users simultaneously visiting the virtual museum.

6 Conclusion

This paper presented a location-based VR framework and a VR museum as a proof-of-concept. We demonstrated its viability and discussed its specific features and expected benefits. The current version of the system is now ready to be used as an experimental platform to empirically study the benefits, limitations and challenges of a *fully* VR museum. Our future experiments will measure the actual affordances on users' enjoyment and learning outcomes. We also exploring potential framework improvement by including novel features such as the integration of complex avatar representations and social behavior augmentation techniques as suggested in [RKF+18]. With the recent advent of stand-alone affordable VR headsets with inside-out tracking (such as the *Oculus Quest* [OV19]), the development of location-based VR systems is becoming a reality. The better tracking and simulations quality provided by off-the-shelf VR head is now opening an exciting application domain for VR researchers and users. However, many questions still need to be answered regarding the architecture, affordances, requirements and effects of such VR applications. We hope our contribution will help the community to build, design and explore future location-based VR systems.

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