Virtual Reality Training Platform: a proposal for heavy machinery operators in immersive environments

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Abstract. Training in a virtual environment can augment the current methods of professional's training, preparing them better for possible situations in the field of work while taking advantage of Virtual Reality (VR) benefits. This paper proposes a cost-effective immersive VR platform designed in real-context usage, consisting of an authoring tool that permits the creation and manipulation of training courses and the execution of these courses in an immersive environment. Accomplishing a good training experience in an immersive simulation requires an equilibrium between the simulator performance and the virtual world aesthetics quality. Thus, in addition to presenting the development of the proposed training platform based on Unity technologies, this paper describes an objective performance evaluation of a virtual training scene using the different render pipelines and across immersive and non-immersive setups. Results confirmed the platform's viability and revealed that the rendering pipeline should be defined according to the display device used.

Keywords: virtual reality, training, authoring tool

1 Introduction

Immersive virtual reality (VR), a technology for creating computer-generated worlds, allows the simulation of the thinkable and the creation of the unthinkable. These worlds have been used successfully in the most diverse areas of applications, such as entertainment, education, or training of professionals in areas ranging from first responder [1], medical staff [2], industrial workers [3], and military. In this last case of application, the real-world training courses are augmented with digital ones, where the most dangerous, complicated, or even life-threatening situations are recreated in a controlled environment without placing the trainee in harm [4]; as stated by [5], VR is a promising training tool for industrial workers, as long the simulation meets high levels of realism and is immersive as possible without compromising the learning, turning into a valid training method.

The more the industry specializes, the more it is critical that its professionals have proper qualifications to execute their tasks, the current methods of training that utilise simulations are dominated by a non-immersive interaction. However, only recently, it started to be incorporated with immersive technologies to achieve better professional training [6, 7], but it is still at an early stage due to the associated costs of creating and maintaining this type of technology, creating a barrier to its adoption since companies have to allocate resources to guarantee that the trainees get proper learning [8, 9], resulting in a low adherence to these technologies [10]; when compared with the current training methods, was proved to be a high-success solution in the training of technicians [11]. This method offers companies the advantage of not needing to pause production or allocate trainers since the exercises are permanently available, granting greater control over them and an increase in safety [8, 12].

To reduce the costs of the development of VR training programs, authoring tools (AT) can be created, making available to the trainers the tools for the creation and maintenance of the training courses. These can be combined with visual program representation to build interactive experiences [13], with modular architecture and visual scripting tools, enhancing the visualization and speeding up the creation of content [14]. However, these tools do not offer the possibility to reuse or import new assets limiting is life-cycle of operability [15].

The AT developed in [16] offer a fully immersive interaction, where the users interact with the courses without leaving the virtual world, import and prepare new 3D models to be used and create the training steps by recording the trainer choreography while he performs training procedure. However, the models imported could not be modified inside the tool, requiring the trainer to repeat the process to fix the model.

Training to operate heavy machinery can be expensive due to the maintenance of the equipment and dangerous when they are wrongly handled. To alleviate this, [17] developed a VR training simulator about the operation of forklifts, where through the usage of controllers similar to the real ones, the users could learn how to operate them safely inside of a controlled environment since it was proven to be an effective training method by a certified specialist operator.

This paper tackles the adoption barrier by proposing a VR training platform with an AT for anyone to create personalized virtual training scenarios without requiring specialized knowledge. The proposal platform and its development will increase the availability of training, making it safer to execute and improving employee resilience/readiness for different real-world situations.

In the remaining paper, Section 2 presents the proposal for an immersive VR-based training platform for the industry, complemented by an AT for creating and managing immersive VR courses. Section 3 sets forth the proposal development by testing different rendering solutions. Ending with the taken decisions and future work for the training platform development.

2 Immersive VR Training Platform

Training platforms require careful planning before their development as training programs involve different dimensions of a corporation ranging from the managing perspective of who supervises the training to the individual particularities of each collaborator that undergoes the corporate training. This section proposes an immersive VR training platform designed based on real-context usage, with the long-term vision of creating a fully modular VR training platform that can be adopted by any stakeholder willing to adopt a VR training platform for corporate training.

2.1 Case study specifications

The case study was designed together with company CUTPLANT Solutions, S. A. [18], a company that is devoted to the design, development and sale of machinery and equipment for the agricultural and forestry sectors. The purpose of this training platform accents in the preparation of the respective professionals for real-life situations, permitting an improvement in the repair time of the forest machines by reducing the number of breakdowns. To achieve it, the trainees will face a series of tasks in the immersive simulation, where the corresponding performance is matched with the previously determined key performance indicators.

The proposed training platform will focus on immersive VR training with forest machines, where it was established that it will have two types of users: trainers and trainees. It is expected that trainers can create and manipulate the training courses, the environments and the forest machines, and re-purpose training courses with new heavy equipment supported through a model importation system. It is expected also that trainers can monitor the trainees during the execution of the training courses, as well as consult past executed training courses to augment the evaluation of the trainee. The trainees, as the name suggests, will be able to undergo the training courses, perform the required tasks to fulfil the simulation, and learn about the operation and maintenance of the respective heavy equipment. The previously stated objectives serve as guidelines for the proposed training platform development; in conjunction with the analysed related work, the following requirements can be defined where the platform must allow:

- The creation and storage of the training courses.
- The creation of the training environments where the course will take place.
- The definition of the environment terrain orography, creating deformations, inclinations, or even flattening the land.
- The scattering of different types of the trees through the environment.
- The importation of 3D models of the harvester head.
- The definition of the period of the day for the training courses, indicating the time of the day where the operation will take place.
- To load the previously created and stored training courses.

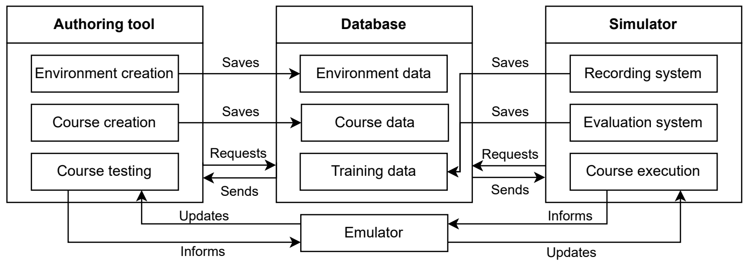

Fig. 1: Training platform integration of the development modules.

– The execution of the training courses in an immersive mode with 90fps.
– The representation of the forest machine functionality in the virtual world, simulating the rotation and oscillation when it is operated.
– The simulation of the forest machine physics during his locomotion and rotation, producing the corresponding sounds.
– The simulation of the harvest head functionality with the physics and sounds.
– To record the training courses execution for a post evaluation of the user.
– Be generic and scalable to newly developed products.

Based on the above-identified requirements, the platform was designed to be divided into two modules: authoring tool and simulator. The first one will emphasize the creation and management of the immersive training courses, and the second one the execution of these courses while evaluating the performance of the trainee (Fig.1).

2.2 Authoring tool

To achieve the previous stated requirements, the development of the AT is going to be divided into several modules to fulfil each one of them. This way, dependencies between modules are not created and could be developed independently granting modularity to the process (Fig.2). The Environments module will focus on the development of tools and features to accommodate the need to design the environments for the immersive training courses; the Asset import will allow the trainer to import new assets of the forest machine, preparing it to be operated on the training course. The features of the Courses module focus on the creation and maintenance of courses, where the trainer defines the environment, forest machine, and the success criteria, among others; the trainer could verify the credibility of the course on the Course testing module, simulating the functionality of the forest machine on the corresponding course.

In an industrial environment, the companies produce 3D models of the respective products, allowing the modification, analysis, and optimization of the same products before even being created. These models can be designed in Computer-aided design (CAD), becoming a challenge when used for the training of professionals since they provide an inefficient performance in a virtual environment,

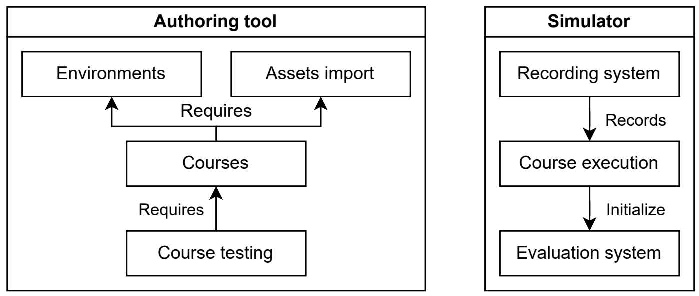

Fig. 2: Integration of the Authoring tool and Simulator modules.

or the constituted parts are not split for the user interaction. To solve these complications, a middleware is required to allow the trainers to transform the already existing 3D models into models that can be imported by the AT. Since CAD remains an industry standard, if the immersive training platforms can accommodate the respective models without modifying the existing systems, it will encourage the adoption of these training technologies.

2.3 Simulator

The development of the simulator will be divided into smaller parts to guarantee its modularity and independent development (Fig.2), where the module Course execution and the Course testing module from the AT will be developed at the same time since they share the concept for the execution of the course. In these, the information from the course will be loaded into the virtual world, presenting to the user the virtual environment, the forest machine, and the defined tasks, among others. During these simulations the virtual forest machines will react based on the instructions given by the user through the controllers, producing visual, auditory, and haptic feedback. Another module will focus on the evaluation of the trainee at the end of the training experience, where a training report is created containing the respective course, the time that took to complete the tasks, the outcome for each of the tasks, as well the trainee grades for that course. To help the trainer with the evaluation of the trainee, the training session will be recorded and stored, then played back when needed.

3 Development of the VR Training Platform

The proposed VR training platform was developed using the game engine Unity since it allows a feasible development of immersive VR experiences. With this engine the authors design and implement the base structure for the AT and the Simulator, connecting them to a database for sharing the training data.

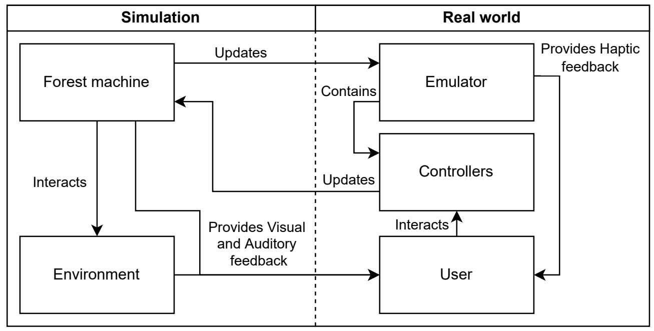

Fig. 3: Integration of the Simulator with the Emulator.

Fig. 4: Temporary terrain orography interface on the authoring tool.

3.1 Authoring Tool

In this, a trainer has access to the module of Environments, where he can manage the existing environments or create new ones; with the help of resizable brushes, he can modify the terrain orography, creating deformations and inclinations, as well as flatten the same land (Fig.4); to increase the environment realism, forest elements can be scattered through the terrain randomly, with resizable brushes or placed one by one, some of this elements serve as targets for the interaction during the Simulation.

Within the AT, the trainer it is permitted to import new 3D models of harvest heads attachments for forest machines. The process starts when the desired head attachment CAD file was chosen and processed through a middleware system to one of the extensions .fbx or .obj, allowing the trainer to import it to the AT. Once loaded the trainer has to identify each of the harvest head parts with the respective tag from the available ones, this permits the tool to apply the corresponding functionality to the harvest part; the trainer can adjust the functionality of each harvest part by modifying the available parameters. At this stage, the visual aspect of the head attachment can be modified by changing the corresponding material of the several harvest parts, and the auditory feedback by adding the desired audio to the several harvest parts. When it meets the desired requirements, the trainer can save it and use it on the simulator.

With the previous components available on the AT, the trainer can create new courses or manage the existing ones, indicating the corresponding title and description, associating the desired environment and harvest head, and defining the hour of the day that the course will start.

3.2 Simulator

On the Simulator, is loaded the corresponding environment and the selected harvest head attachment preparing them for the immersive experience. Once ready, the forest machine and the harvesting head will react based on the user input, creating visual and auditory feedback on the different parts and the interaction between the forest machines with the environment and its elements. As represented in the (Fig.3), the user interacts with the controllers presented on the emulator; these are composed of a combination of joysticks, pedals, and buttons that recreate the cabin of a forest machine. The presence of these controller types in the simulated training course will permit the training experience to be more realistic and multisensorial for the user.

3.3 Performance evaluation of rendering pipelines across different VR setups

Achieving the best training experience in the immersive simulation requires an equilibrium between the Simulator performance and the virtual world aesthetic. When it becomes imbalanced, the simulation can become sluggish, impacting the overall experience and the trainee's knowledge retention or even inflicting cybersickness on the trainee. For the proposed training platform the aesthetics tuning was found through a study of a custom scene in different render pipelines available in the Unity engine: the High Definition Render Pipeline (HDRP) provides tools to create applications in high-fidelity graphics on high-end platforms (Fig. 5c), and the Universal Render Pipeline (URP) offers artist-friendly workflows that allow a quickly and easily creation of optimized graphics across a wide range of platforms (Fig. 5b), and the Built-in Render Pipeline that has limited options for customization since it is the general-purpose render pipeline for the engine (Fig. 5a). To assure fairness and reliability of the study results, each one of the custom scenes was executed for a total duration of one minute, in a computer with the following specifications, Intel Core i7-9700k CPU, NVIDIA GeForce RTX 2080 Ti, 16GB of RAM. Since the Simulator application is expected to allow immersive execution, the custom scenes were tested using three different display interfaces, two immersive and the other non-immersive, represented respectively by the head-mounted display (HMD) HTC VIVE, the HMD Oculus Quest 2 and the conventional computer display LG E2242T-BN 22". The proposed training platform it is targeted to achieve 90 frames per second (fps) in the simulation so for this study, the HMD Oculus Quest 2 refresh rate was set to 90Hz, and was tested in the recommended resolution (RR) of 3712x1872 and in the lowest resolution (LR) of 2432x1216.

(a) Built-In (b) URP (c) HDRP

Fig. 5: Visual aesthetics of the different pipelines from the user perspective

Table 1: Display performance for the different render pipelines in fps

	Render pipeline								
	Built-In			URP			HDRP		
Display	avg.	1%	0.1%	avg.	1%	0.1%	avg.	1%	0.1%
Monitor	468	329	147	472	257	101	323	264	102
VIVE	89	82	70	89	85	67	89	83	65
Quest RR	89	81	70	56	40	39	66	42	36
Quest LR	89	82	71	90	70	46	89	81	65

To foment the choice for the pipeline, during these tests was collected for each one of the conditions the average (avg.) frame rate, the worst 1% of frame rate, and the worst 0.1% of frame rate. Each HMD was placed standing still on a platform to avoid human intervention during the tests, granting the same visual perspective of the virtual environment.

Based on the obtained results presented in Table 1, it is possible to conclude that the Built-In pipeline offers a stable performance independently of the immersive display while keeping a pleasant virtual environment. The Universal and High Definition render pipeline provide new tools to create a virtual environment but require higher tailoring of the different settings to achieve the same level of balance of Built-In; the results also showed that the resolution of the immersive displays affects the performance. Consequently, results suggest that built-in render pipeline should be adopted as default, but when more computational power is available, URP or HDRP can and should be privileged.

4 Conclusions

The current paper presents a training platform targeted to optimize the productivity of the trainees by improving the efficacy of the operators and maintenance technicians, reducing the number of breakdowns and improving the time needed for repair. Based on a real case study of a company in the agricultural and forestry sectors, the development of the training platform was divided into Authoring tool and Simulator components, where the users could create and execute the training simulations.

The present study allowed the authors to define the Built-In as the default render pipeline of choice for the proposed training platform development since it performed stable across the tested immersive displays while keeping the aesthetics pleasant. Nevertheless, depending on the computational power of the system, users can adopt a different rendering pipeline

Based on the provided feedback in the interactions with company CUTPLANT SOLUTIONS, S.A., the Authoring tool component from the training platform must allow for registration of the key performance indicators and the success criteria of the courses. The Simulator component needs to be connected with a digital twin system, abstracting the interactions between the Emulator and the simulation and modifying the simulation with new data, such as possible breakdowns. Other sources of sensory feedback will be added to the Emulator, improving the training simulation realism and the user training experience. Such as haptic feedback based on the virtual environment interaction and placing the emulator on a rig with 6 degrees of freedom, allowing it to represent the locomotion of the virtual forest machine through the virtual terrain.

As for future work, the authors are committed to the evolution of the proposed platform by modifying the simulations with data from a digital twin to improve training realism. Validating it in usability, performance and training augmentation with a real-context case study created in partnership with company CUTPLANT SOLUTIONS, S.A., with the professional operators.

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