DEMONSTRATION

A Virtual Reality Simulator for Timber Fabrication Tasks Using Industrial Robotic Arms.

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A Virtual Reality Simulator for Timber Fabrication Tasks Using Industrial Robotic Arms.

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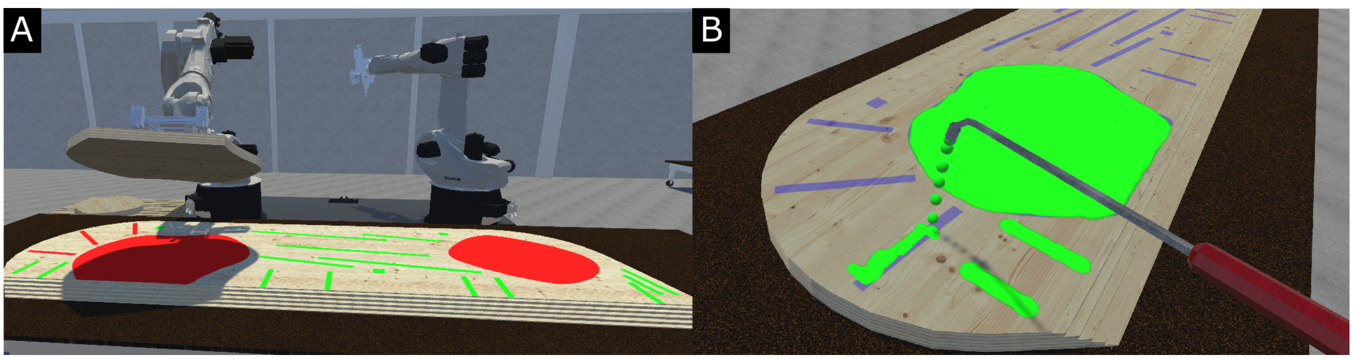

Figure 1: Simulator of the timber fabrication platform, with two industrial robot arms. In A robots perform a pick and place (PNP) operation with a large piece of timber is pictured. In B the application of glue on a surface by a human worker using a glue gun is shown. The table on the platform where the pieces are handled can be moved by the user back and forth to adjust to the robot's reach.

ABSTRACT

Virtual Reality (VR) simulators are well known applications for immersive spaces. When it comes to Human-Robot Collaboration(HRC), training and safety are important aspects that can be supported by simulators. In this demo, we propose a workflow between ROS and a VR application that allows the use of real robot programming plans to control the robot's digital twin. We also provide the results of a short evaluation that was done with 6 experts, where they provided insights for future improvement and use cases. Our demo is the first step towards a full integrated system where path planning and fabrication steps can be tested with users without any of the risk and cost that are involved when using real industrial robots.

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CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; *Empirical studies in interaction design*; • **Applied computing** → Engineering; *Architecture (buildings)*.

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1 INTRODUCTION

Simulators are one of the most common use cases of VR applications. Health, education, sports, and many other topics can benefit from VR main advantages: lower cost and low risk compared to real world scenarios. However, some of the drawbacks still impact the user experience drastically, like the lack of haptic feedback, the limitation of space and the input methods, for example when fine hand gestures are required. Another issue with VR simulators that is less critical but still relevant, is the data similarity between real use cases and simulations. In scenarios where Human-Robot Collaboration (HRC) happens, it would be logical that the data related to the robotic program could be shared between real execution and the immersive simulation. This concept can bring advantages such as saving time developing a path plan that can be used in both situations, and higher fidelity of the movements.

Considering these advantages, we propose integrating a ROS environment, which is used for programming real industrial robot arms, with a VR simulator. Our use case specifically focuss on timber fabrication, which requires some level of automation, but also a lot of involvement from the human workers in the process. When fabricating timber structures, the freedom in their design is high, making it more difficult to automate. Since the robotic arms are expensive and large equipment, having a simulator where all the fabrication steps can be performed beforehand makes sense.

In this demo, we implemented basic input like grabbing objects and pressing virtual buttons using a controller, in addition to more complex tasks like gluing and milling, which we use to simulate the behavior on timber surfaces. Our work contributes as a testbed in which other researchers can implement their simulations using instructions that are already programmed to real robots in an environment where safety, improvements in collaboration and workflow systems can be easily tested and improved, without relying on the physical robotic hardware.

2 RELATED WORK

In terms of combining immersive spaces and robotics, we can mention using Mixed Reality (MR) to teleoperate robots. This can be useful, for example, when an expert is far away from the robot's location or when they need to teach someone else how to operate it. Whitney et. al [5] compared manipulation tasks between immersive and non-immersive environments and found that for tasks that involve more complex manipulation, VR was preferred among the users. Moshayedi et. al. [3] investigated the use of VR for simulating the behavior of Automated Guided Vehicles (AGVs). The simulation helped participants prevent possible navigation issues and better understand the vehicle's path. In addition, using virtual spaces to improve safety when operating robots is also widely explored in the community. As an example, Augmented Reality (AR) has been used to increase the trust in the human agents [4], as well as to make the interaction more transparent to users [2]. AR has also been used to control the robotic workflow and to allow sharing of different tasks between humans and robot [1]

Given the applications mentioned, it is clear that immersive spaces play an important role in HRC from different perspectives, so having a VR simulator able to replicate real instructions is a good way to have a testbed for applications in collaboration scenarios beforehand.

3 IMPLEMENTATION

We divide the implementation into two main aspects: robotic control and task features. We present the integration between ROS and our VR system for robot control. In terms of tasks, we implemented gluing and milling, which are present in typical timber fabrication operations. Gluing can be performed by the robot and by the human, while milling is currently implemented just for humans. Our software was implemented in Unity and C# for all VR components and Python with ROS for all robotic components.

3.1 Robotics

In order to simulate our robots, we split the control of all machines into two separate parts. The controller can be seen as the physical capabilities and firmware of the robots, providing an interface towards the driver. The driver can then be seen as the control unit, providing high-level abstractions for controlling the movements of the robotic arms. This allows the implementation of different control modi for the robotic arms.

The robotic arms receive their commands from ROS, just like the real ones. In this mode, the simulated fabrication platform behaves identically to the physical one. This goes as far as allowing the same programming used for the real robotic arms and the simulated ones. The connection is currently done using Unity Robotics ROS TCP Connector.

3.2 Task features

Two separate interaction features are implemented: gluing and milling. For applying glue on objects, we implemented a texture painting system in which four texture types are supported: color textures, normal maps, metallic maps, and height maps. This allows for various visual representations of glue. By painting directly onto the texture, there is only a fixed performance cost for applying it on the surface.

By using the normal map, even shallow engraving can be visualized. In order to avoid shallow carvings to override deeper carvings, a depth value has to be stored for each stroke. This is done by reinterpreting the texture's alpha channel as a depth buffer. In addition to this, it is possible to set a brush texture, which can be used as a stamp. The glue application uses a brush, which applies glue where the brush collides with the work surface. Alternatively, a glue gun can be used, which spawns glue blobs at its tip with a configured initial velocity as long as the controller trigger is pressed.

A volumetric modeling technique is implemented using an octree structure to enable milling into objects. Each node of the tree contains a flag which is set if the voxel corresponding to the leaf should be considered as empty. Inner nodes track the number of children marked, to allow for early termination in the collision system. Each leaf node contains a bitmask, storing information if the sides of that node are part of the model's border.

We implemented a custom two-phase collision system to mark the nodes. To increase performance and utilize the inherent structure of the octree object, all bounding boxes are axis aligned to the object space of the workpiece. This way, it is possible to use the octree nodes directly as bounding boxes. By using the tree structure, it is then also possible to utilize early termination in case the cell is already fully marked. The narrow phase is then implemented using the Gilbert–Johnson–Keerthi (GJK) distance algorithm on the candidates identified in the broad phase.

The marked octree is rendered by generating a mesh from the octree object. For this, each unmarked leaf node sharing a side with a marked node is checked. Then, based on the resolution of the neighbors, a suitable mesh pattern is selected.

Further interactions required, such as picking up objects and placing them in specific locations, are already sufficiently implemented by Unity.

3.3 Control Flow

The control flow of the study tasks is implemented using a finite-state machine. The state machine is automatically synchronized between Unity and ROS. In ROS, the finite state machine is implemented as a custom ROS package. This package handles all the planning of all movements of every robot, as well as the position of portal cranes installed in the virtual location. In order to simplify developing new tasks, we implemented simplified wrappers for handling our robotic platforms. This allows us to use an object-oriented programming paradigm for moving the robots.

4 USER EVALUATION

We evaluated our simulation with a small expert user study with six participants. The selected participants were researchers, architects, and civil engineers aged 29 and 42. All of them previously at least observed the manufacturing processes involving the real fabrication platform. The study was divided into three parts: a minimal tutorial on the VR interactions, a fabrication workflow, and a free trial of the task features implemented. Once the fabrication simulation was completed, the participants were allowed to explore the simulation freely. In this final phase, they explored features not required for the fabrication, like milling, as well as static models of the constructed building and the entire robotics lab. After completing all tasks, the participants were asked to fill out a questionnaire consisting of questions about demographics, prior experience with the robotic platform simulated by us and virtual reality, as well as the questions of the System Usability Scale (SUS) questionnaire.

5 RESULTS AND DISCUSSION

The score of the SUS questionnaire was 75, which is considered acceptable for interfaces. In addition, we got rather diverse qualitative feedback from the users. Some were very focused on how we displayed the instructions for the tasks rather than the interaction with the robots themselves. Others had more experience in the fabrication process and were more concerned about moving around in space and interacting with the world than with the instructions. For this user study, we displayed the instructions for the task on the wall, more or less like a big projector would work, which should be improved for later versions. Perhaps also adding a tutorial with more interactive tasks would make sense to make users that are not so familiar with VR more comfortable. In addition, we noticed that the users missed the haptic feedback that was present and that the tasks were "easier" than the real ones because of that. We plan to incorporate haptic feedback in future simulator versions and iteratively test it again.

6 CONCLUSION AND FUTURE WORK

Our work demonstrated how the integration between industrial robots and a virtual reality simulation can work using the exact robotic programming instructions for actual tasks. To evaluate the usability of our simulator, we performed a small study where we collected usability feedback through questionnaires and unstructured interviews. The study was done mainly with experts in robotics and timber fabrication. We conclude that our implementation is the first step to an automated simulator that can be used to test robotic planning and as a testbed for novice users that have never worked with robot platforms yet. In future work, we would like to expand the support to collaborative setups on both robot and human sides. On top of that, implementing support for visualizations would be an essential point, as situated visualization becomes a more relevant topic and is suited to immersive spaces like ours.

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