VR Pre-operation Inspection Training Simulator Using Haptic Gloves

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Abstract

The use of Virtual Reality (VR) training to upskill the workforce and improve efficiency has been rapidly growing in many sectors, including mining and construction. VR training simulators provide creative solutions to the pain points faced by the current training modules in the mining industry. We have developed a virtual education and training module with the development of a VR pre-operation (pre-op) inspection training simulator using haptic technology. Traditional training methods often fall short due to non-engaging classroom sessions, extensive manuals, and limited hands-on experience, compounded by harsh weather conditions and high operational costs. Our VR pre-op inspection training simulator aims to revolutionize training by providing recruits with efficient, self-paced learning experiences ultimately increasing efficiency and reducing training time. By leveraging VR and haptic technology, we offer valuable insights to the Human-Computer Interaction (HCI) community, highlighting the potential benefits of VR training scenarios in mining and construction. Through our research, we explore user behavior, design constraints for VR and haptic interfaces, and accessibility requirements, paving the way for enhanced training methodologies in these industries.

1 Introduction

New recruits undergo thorough training in the mining industry to acquire expertise in their specific roles. One important role is that of a haul truck operator. Safety and efficiency in haul truck operation is pivotal in the mine. Before a truck operator begins driving their truck, they need to perform a pre-operation inspection to make sure all the components of the truck are in good order. The purpose of the pre-operation (pre-op) inspection is to check the working condition of the truck components and the safety of the trucks' surrounding area. This pre-op inspection involves the truck operator meticulously examining components in each zone of the haul truck with a comprehensive checklist. The truck operator also assesses the truck's surrounding area before operating the truck in the mine. The pre-op inspection assures that the truck doesn't malfunction during its operation, ultimately guaranteeing worker safety and smooth mining operations in the mines.

The entire process is carried out by the truck operator at the mining site. Often times the truck operator is by themselves. As a result, the pre-op inspection

Figure 1: *Safety dojo level: The starting point of the training module where users wear virtual safety gear. Here they have an option to choose between different machines on which they want to perform the pre-op inspection training. They can also select if they want a tutorial session or directly want to start the VR pre-op inspection training.*

in a crucial part of safety. The new recruits undergo training to proficiently carry out the pre-operation inspection process. According to the subject matter experts, the training includes classroom sessions featuring PowerPoint presentations, 3D animated videos illustrating the truck's intricacies, and supplemental reading materials like shop/operational manuals. These classroom sessions typically last 3 to 5 days. Subsequently, trainees engage in hands-on sessions with the haul truck at the mine site under the guidance of experienced truck operator trainers. This practical exposure allows them to observe and inspect real components, gauge the truck's size and scale, and gain valuable insights into and understand the pre-operation inspection process. However, there are issues regarding the current training modules, used to teach a new recruit about pre-op inspections.

During the research phase, the truck operator trainers highlighted certain issues with the current training method. The traditional classroom teaching method brings certain challenges such as lack of visual elements, that impact the recruit's engagement in the training and result in lesser knowledge transfer. As explained by subject-matter experts, many recruits neglect reading shop manuals and operation and maintenance manuals because they range from a few hundred to a few thousand pages long. This leads to reduced knowledge retention among new recruits. Rettinger [19] emphasizes that while one-on-one guidance is suitable for smaller groups, larger groups (5-10 recruits) put a strain on both the trainer and resources. Taking these trucks out of operation and interrupting the mining process incurs a significant loss of time and money for the company. There are not many opportunities for a new recruit to deeply understand the truck. Trainers also face adverse weather conditions. Often times these trainers may be in extreme heat 120F or extreme cold -60F for multiple days training groups of new recruits. This is difficult for the trainers. These restrictions result in recruits spending less time on-site with the truck and not getting a chance to review or implement all of the material learned.

VR significantly contributes to the mining and construction sectors, particularly in safety training, simulation, operational planning, equipment maintenance, inspection, and data visualization. Higher data visualization abilities improve problem-solving skills, and VR enhances spatial awareness [29, 6, 9]. According to Piitulainen, Roosa [17] VR provides physical safety, reduces the feeling of anxiety, and lets the users express themselves freely in the virtual space. Our project, "VR Pre-operation Inspection Training Simulator Using Haptic Gloves," leverages VR and haptic gloves, developed by HaptX [1], to revolutionize operator training efficiency and improve learning outcomes for new recruits. The project's primary objective is to grant repeatable pre-op inspection training, that enables recruits to practice, learn, and train at their own pace. The haptic gloves allow new recruits to feel and more deeply understand the truck they are operating. We developed a VR Pre-Operation Inspection experience to solve the challenges faced by the truck operator trainers.

The team contributes valuable design insights to the HCI community by sharing insights learned during the development of a VR experience in mining and suggesting potential benefits for training scenarios in the mining and construction industry. These insights encompass the behavior of the target audience, design constraints for VR, and accessibility requirements for mining personnel.

2 Related Works

In the past decade, many researchers and projects have attempted to implement virtual reality in the field of construction and mining.

2.1 Immersion and Interaction:

For any VR experience, immersion is an important aspect as it provides a higher sense of reality to the user. Enhancing immersion promotes natural human movements and behaviors, making the virtual experience similar to real-life experience. Here are some research and projects worth mentioning that used various VR technologies to achieve immersion.

For instance, the Razer Hydra system uses controllers and a PC screen. It allows real-time interaction with the virtual environment using smart controllers to create depth and immersion. However, it still presents content on a 2D computer screen [8]. In Sekizuka's work [20], a PC-based simulation uses a camera, installed inside a toy excavator and provides an operator's point-of-view (POV) to enhance immersion. This method too, displays output on a 2D screen. The excavator's movements are controlled using a joystick to approximate the excavator's controls. In Songyue's project [13], LCD screens were placed in such a way that it formed a closed cabin of the machine. It simulates the view from an excavator's seat. To mimic the cabins' motion and have precise positioning and load alignment, a hexapod steward motion platform with 6 degrees of freedom was utilized. Another noteworthy immersion technique is the cave automatic virtual environment (CAVE) [12], which uses 3D projectors to

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[1] https://haptx.com/dk2-release/

project content onto the walls, floor, and ceiling of an empty room, thus creating a highly immersive virtual environment. Many other projects incorporated Head-Mounted Display devices [8, 28, 4, 16, 30] to enhance immersion. However, these works did not explicitly address the degree of freedom provided to their users.

In contrast, this project utilizes the Valve Index HMD and controllers. This provides complete immersion by allowing users to feel as if they are standing in an actual mining site. Compared to the immersion technologies mentioned earlier [12, 13, 20, 8], Valve Index offers freedom of movement in every direction, and enables users to move in any direction without restrictions, similar to real life. Additionally, to give users a sense of touch and enhance the haptic sensation, the team has integrated haptic gloves, developed by HaptX, to improve immersion levels. These haptic gloves provide a haptic sensation to the user's hands when they interact with virtual objects in the scene. The haptic gloves also offer individual finger tracking that allows for more natural hand gestures and movements, resulting in enhanced realism and immersion of the experience.

2.2 Teaching and Knowledge Assessment:

The safety and efficiency of pre-operation inspection depend on the training method employed. VR training has been proven to be more efficient than traditional methods as it provides clearer task objectives and faster, more accurate task completion [9]. Truck operator trainers explained that new recruits undergo classroom sessions that include PowerPoint presentations, traditional teaching methods, and 3D animation videos showcasing machine operations. This process is then followed by hands-on experience at the mining site in extreme weather conditions, spanning 3-5 days. Tichon highlights the need for more worker involvement and hands-on experience in current teaching methods [24].

Qualitative research is crucial to assess the knowledge gained through VR training. Research about VR in meditation measured the learning outcomes by evaluating changes in participants' mindfulness and stress levels using scales like MAAS, CAMS-R, and PSS [7]. Trainee characteristics, training design, and work environment are factors that consistently influence the transfer of knowledge among the trainees [27]. Paweł Strojny suggests measuring knowledge through tests, quizes and assessing skills in the same virtual world can prove to be much more helpful [22].

Akbulut explains that besides entertainment, VR is fundamentally applied to training and teaching for safety [1]. VR has the potential to enhance natural interaction and provide a more realistic simulation experience [10]. VR training systems in mining and construction machinery operations, such as VR Flier and others have significantly reduced training time and costs while ensuring the safety of the users [26, 27]. Our project prioritizes immersive, hands-on learning experiences in VR. Starting with the tutorial session the experience introduces users to the VR environment and interactions. Users then perform a pre-op inspection on a life-size haul truck within the VR environment, inspecting components and assessing their condition through interaction. Following the virtual inspection, a knowledge assessment quiz evaluates users on the haul truck inspection.

2.3 Realistic Interactions and Scenarios:

VR interactions play a pivotal role in determining immersion levels of the experience. Scenes and interactions guide users in anticipating actions needed to make changes in the virtual environment. Zhang emphasizes the role of VR technology in constructing scenes and objects, that offer a multisensory experience for enhanced immersion during interactions [28]. Some works also provide scenarios for general information and guidance in virtual mines [11], or training scenarios regarding self-escape or proximity detection [3]. Others incorporate input devices such as joysticks [13, 8, 28, 2, 20, 21] and controllers [4, 15, 14] for intuitive interactions like traversal or object selection. These inputs are distinct from the conventional mouse and keyboard and are widely preferred. However, some simulators either lack or oversimplify genuine machinery dynamics, failing to find a balance between the model's fidelity and real-world physics [13].

Although some papers discuss haptic feedback to emulate real interactions [25], there is not enough research addressing its use within the mining and construction industry, except for [8].

In contrast, our project utilizes haptic gloves to enable users to replicate realistic interactions encountered in real-life scenarios. Tasks include removing lodged rocks, evading falling mud blocks, tightening bolts, and handling and lifting components. These interactions empower users to engage in natural and realistic gestures and movements, effectively simulating challenges faced by workers on the mining site. This approach enhances realism and, consequently, immersion in the training experience.

3 Design Process

The aim of the research was to understand the pre-op inspection process and training method for truck operators that would help to develop a training module for the recruits at the mining company. Qualitative research methods, such as focused group sessions, online Zoom meetings, site visits, and usability testing, were used to gather insights from truck operator trainers. These methods aimed to gather insights from experts in the field of pre-op inspections and training modules. The participants were the company representatives and the truck operator trainers from the mining company.

As shown in Figure.2, focus group session features our team, the trainers, and the stakeholders having dynamic discussions. These focus group sessions highlighted the pain points of the current training module and suggested improvements for the new training module. These discussions informed us about pain points like recruits not reading the operation and maintenance manuals because they are thousands of pages long. Less engagement in classroom training sessions results in reduced knowledge retention among recruits. Weather challenges such as conducting hands-on training in extreme heat 120F or extreme cold -60F are difficult for longer duration. Inadequate hands-on training with haul trucks is another reason for less knowledge retention in new recruits.

Considering the busy schedule and travel limitations of the stakeholders, bi-weekly Zoom meetings were incorporated. Figure.3 shows how Zoom meetings were conducted to bridge communication gaps between the team and the mining company. This method allowed seamless sharing of the team's progress. At the

Figure 2: *Focus Group Sessions: Focus group session being conducted by the lab director. The stakeholders (sitting in front) had a dynamic discussion with our lab director. The session discussed the current pain points of the training module and the changes they would like to see in the VR version of the inspection training.*

same time, the stakeholders could also express their suggestions and concerns regarding the progress. This contributed to collaboration and enhanced efficiency among both parties. Usability testing assessed the product's functionality. This is discussed further in the design phases section.

To gain a deep understanding of the mining industry, the team visited one of the mining sites, where a few team members participated in the truck operator training module. They experienced the classroom sessions, 3D animated videos of the truck's working, reading manuals, and also got hands-on machine operation of the haul truck under experts' supervision. Figure 4 shows the team learning about the details of pre-op inspection from the trainer. The team installed GoPro cameras to capture the working of the truck for its incorporation into the VR environment. The visit also provided insights into training techniques that could be included in the pre-op inspection.

These research methods yielded valuable information on pain points, challenges, and expectations of the pre-op inspection process. Haptic gloves provided accurate tracking and tactile feedback to the user's fingers. This made natural hand movements possible in the VR environment resulting in enhanced learning and user engagement for new recruits.

4 Design Phases

Throughout the 12-month project duration, the project went through three major design phase revisions that were based on feedback from mining company personnel. Their valuable input during visits, usability tests and discussions improved our decision-making process, which enhanced both the project's design and the broader design community. This collaborative effort significantly

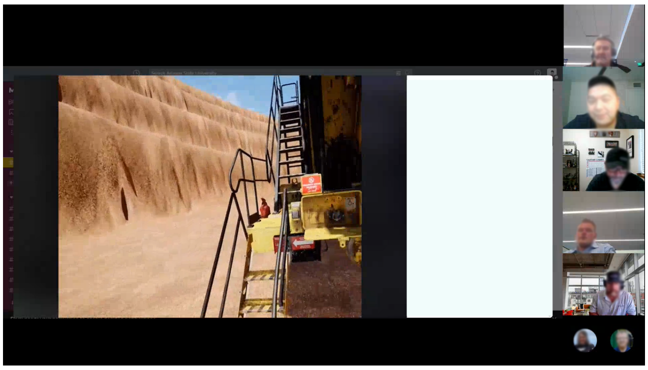

Figure 3: *Considering the busy schedule and travel limitations of the stakeholders, zoom meetings were incorporated to bridge the communication between our team and the stakeholders. These meetings shared the project's progress with the stakeholders and also let them suggest feedback, comments, and concerns regarding the project's progress.*

Figure 4: *Our team members visited one of the company's mine sites and participated in hands-on training about pre-op inspection. In front is the truck operator trainer explaining the intricacies of the pre-op inspection to our team members.*

contributed to the overall success of the project.

4.1 Implementation:

In a project of this nature, precise device tracking is crucial to prevent motion sickness and dizziness. To mitigate these risks, we selected top-tier hardware, focusing on the Valve Index VR headset and controllers. Haptic feedback was facilitated by HaptX Gloves, offering nuanced sensations to individual fingers based on VR interactions. Accurate tracking of headsets, controllers, and gloves was ensured through Steam VR base stations. The immersive experience was developed using the Unreal Game Engine 4.27.

4.2 Phase 1:

The team's aim in phase 1 was to develop a solid foundation for the Virtual Reality (VR) pre-op inspection prototype. The primary objectives were to validate the feasibility of haptic gloves and challenge the team's assumptions about hardware implementation. A VR prototype was crafted to simulate the pre-op inspection process, integrating realistic and interactive elements. The team sought confirmation from the stakeholders, that the projects' progress and direction aligned with their expectations. Key goals of this phase included developing a VR pre-op inspection prototype, gaining insights into haptic interaction, and honing the ability to design effective interfaces for haptic components.

The team's learning objectives were to integrate the haptic gloves into the experience, understand user interactions within the VR space, and design UI for haptic components. The VR pre-op inspection prototype gave the users, a real look-alike of the mining environment with a detailed haul truck model. Haptic gloves were another important aspect of the experience. The incorporation of haptic gloves served as both a technical proof of concept and a means to offer users hands-on experience. The gloves enabled the users to explore designated zones and components with a tangible haptic sensation.

To replicate the real-world pre-op inspection checklist, huge banner-like checklists were introduced at specific locations in each zone around the virtual truck, shown in Figure 5 . This checklist provided truck operators with specific component names to inspect within each zone of the truck. The recruits would then inspect the components for safety listed in the virtual checklist. However, the checklist was too large, non-interactive, and immovable, obstructing a significant portion of the user's field of view. Recognizing this issue, the team proposed a solution, discussed in phase 2, that allows users to open and close the checklist according to their convenience.

Recognizing the limitations of physical space in training facilities, the team introduced a teleportation feature in the form of a map. This map would enable users to explore the truck from various sides and zones. At this stage, the teleportation feature limited the users to explore only 4 truck zones: the isolation station, front-left wheel, rear-left wheel, and the hydraulic tank between the two left wheels. However, this feature required another person's assistance to teleport the user and was operated through keyboard button inputs (1, T, Y, U) representing each of the four zones. Interference of another person in the experience raised concerns about user autonomy and user control. The solution

Figure 5: *Checklist feature in phase 1: The checklist was a huge banner placed in the virtual mines. It included the names of the damaged components that needed to be inspected in each zone. This variation was non-interactive and immovable.*

to this issue (discussed in phase 2) grants users autonomy and control over teleportation, allowing them to travel back and forth freely in every zone.

The haptic gloves were an important aspect of the experience as they enabled users to feel a haptic sensation when they interacted with virtual objects. Interactive elements included the air bubble on the tire, gripping the staircase railing, and lifting the ladder, enhancing realism and user engagement. Additional teleportation zones were planned and implemented in the next phase, based on the feedback received from the stakeholders. Despite the absence of a structured user flow in this phase, the experience effectively communicated the size and scale of the pre-op inspection, delivering a captivating and immersive VR training environment.

4.3 Phase 2:

In the second phase, the team worked to improve the VR experience based on valuable stakeholder feedback and the lessons learned from the testing session of the initial phase. The primary objectives included implementing changes suggested by the stakeholders, enhancing user autonomy within the VR environment, and elevating the overall user experience.

The goal was to introduce meaningful modifications and ensure that the training module was aligned seamlessly with the needs of the mining industry and provided a better user experience. The team introduced a structured user flow that started with a safety dojo room. This was done to raise safety awareness among the users. Users wore virtual safety gear like a helmet, a safety vest, and safety shoes, before starting the actual pre-op inspection training. This structured user flow not only added realism but also served as a robust onboarding process for users.

The learning objectives of Phase 2 focused on understanding users' experience with autonomous controls and interactive elements, such as checklists and mini-maps. Additionally, the focus was also on evaluating the impact of interactive elements that depict real-life scenarios, on the effectiveness of training and user experience.

The previous checklist was too large, non-interactive, and obstructed the field of view of the user. To eliminate those issues, the updated checklist was now operated using a button and anchored on the user's left wrist. This allowed the users to open and close the checklist according to their convenience.

Figure 6 shows the size of the checklist being reduced and had more interactive elements, resembling a modern tablet screen. This facilitated a seamless replication of the real-world checklist, used in the actual pre-op inspection and was easier to use than its previous version. It displayed the component's names followed by checkboxes named "inspected" and "damaged" to determine the components' condition. Clicking on the appropriate checkbox using their finger updated the component's condition in the checklist. This modification eliminated the issue of visibility obstruction. Also, anchoring it to the wrist ensured that it moved with the user's hand, providing constant visibility when in use.

Additionally, a toggle label button was introduced that provided easy identification of the component's locations on the truck, just like a textbook diagram with labels. However, the bulkiness of the gloves made it hard for users to press the wrist button. This forced users to perform extreme physical movements to reach the button, which isn't how people normally move in daily life. As a result, the experience felt less natural for users.

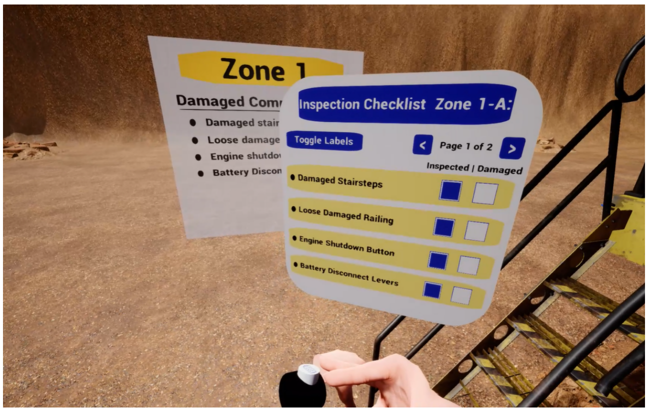

Figure 6: *Checklist feature in phase 2: Checklist in phase 2 was smaller, interactive, and anchored to the user's left wrist. Users could open and close the checklist according to their convenience. It included the names of components followed by two checkboxes to determine the component's condition. It also included a toggle label feature that would point out the location of every component in that zone.*

To give users control over their actions and eliminate external assistance, the teleportation feature was introduced in the form of a mini-map. It was operated by a button on the user's right wrist. This solution allowed users to travel to 20 different subzones effortlessly. Users could now travel back and forth and re-visit subzones as many times as they wanted, to check their work or reinspect components. Each zone acted as a clickable button labeled as ”Zone (number),” and each zone had 3-4 sub-zones (A, B, C, D). To teleport to another zone, users would click on the desired zone and then click on the corresponding letter of the desired subzone as shown in Figure 7 . However, bulky gloves and a small UI caused users to accidentally click on adjacent zones or subzones, teleporting them to a different location. Additionally, the letters for the subzones were placed on top of the truck zone buttons, which took up a lot of space and made the map smaller and more challenging to use.

Figure 7: *Teleportation feature in phase 2: The mini-map allows access to 20 different sub-zones. Users could travel back and forth in any zone, as many times as they wished. To teleport, users would click on a desired zone and then on the alphabet corresponding to the desired sub-zone.*

Interactive elements enriched the realism of the VR experience. It allowed users to engage in activities like sensing tire bubbles, grasping railings, hoisting ladders, tightening lug nuts, and addressing issues such as falling mud blocks, oil spills, and lodged rocks. At the end, to gauge the trainee’s progress, a knowledge assessment quiz was introduced. It consisted of 5 questions to evaluate the trainee’s understanding of the pre-op inspection. This made it easier for the operator trainers to decide which recruit was ready and who required more training.

Insights from this phase highlighted knowledge gaps in recruits regarding specific haul trucks. This knowledge gap stemmed from recruits either not reading the OMM/shop manual, as they are thousands of pages long, or transitioning from a different company with a different truck nomenclature. Navigation and interaction challenges were also observed for users over 40 years old. Phase 3 aimed to address these challenges innovatively by educating recruits about truck components and designing a more intuitive interface for enhanced user experience.

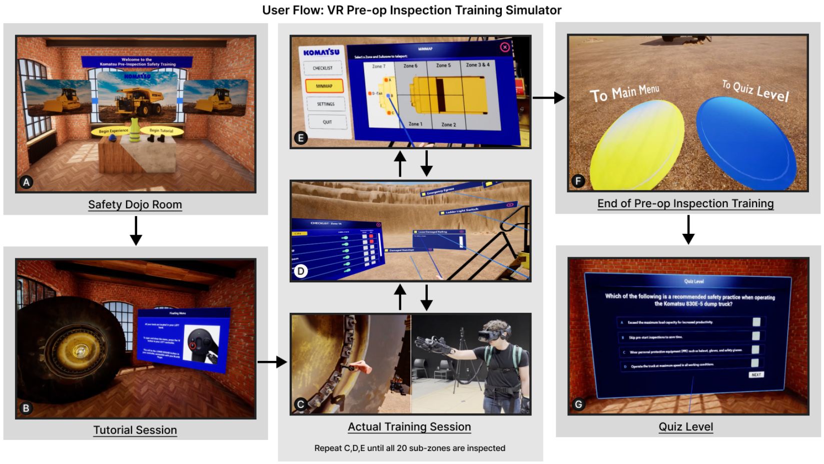

Figure 8: *User flow of Komatsu Haptics: (A) Safety dojo room: Users start the experience by putting on the virtual safety gear, select the machine to perform a pre-op inspection on, and either begin the experience or get trained in the tutorial session. (B) The hands-on tutorial session trains the user to get familiar with VR interactions. (C) The user inspects the components using the haptic gloves. (D) The user utilizes the toggle label feature to locate the component, get its description, and update the component condition in the checklist using checkboxes. (E) The teleportation feature allows users to travel back and forth in any zone to carry out inspections. (F) In the end, users can quit the experience by clicking the main menu or take a quiz to assess their performance. (G) The quiz section where users answer MCQs related to the pre-op inspection.*

4.4 Phase 3:

Phase 3 was the current and final stage of the project and Fig 8 represents the current user flow of the training session. The primary aim was to resolve issues related to haptic gloves and user interface (UI) that were observed during usability testing of the previous phases. Incorporating additional features based on stakeholder and expert feedback was crucial as it enhanced the overall effectiveness of the training module. Simultaneously, the team sought to improve the visual aesthetics of the UI as the previous version seemed visually inconsistent. The new UI was aligned with modern design principles and adheres to the company's brand style guide. This was done to rectify the previous UI's lack of visual appeal and immersive quality. The purpose of phase 3 was to resolve challenges and elevate the overall training experience by introducing innovative solutions and delivering an improved and polished VR pre-op training simulator.

The learning objectives of the team were to discover innovative solutions to address users' challenges and carefully observe how users reacted to these new solutions. Additionally, the team delved into understanding the various interaction options in VR. Actions that were easy and intuitive were finalized and incorporated, ultimately reducing errors and mistakes like accidental clicks.

The bulkiness of the gloves caused users to accidentally click adjacent buttons instead of the desired one resulting in user frustration. To eliminate user frustration, a shift was made from tactile button pressing to utilizing a laser-clicking method i.e. aim-and-click, for UI interaction. The decision to include a laser-clicking method was adopted because of its familiarity. Users use the aim-and-click phenomenon (mouse cursor) every day on their laptops and desktops. Using this technique, users could now click buttons by pointing the laser at their desired target and doing click action with their right thumb and index finger. The laser is active only when the menu is open. A hover effect was added to communicate the target to which the user was pointing. This provided clear feedback to the user. This also avoided accidental clicking of wrong buttons and prevented extreme physical movements done to click a button in both the virtual and real world, reducing the risk of accidents.

Previously, the users were confused between the positions of the checklist and the mini-map buttons. As a solution, the interactive UI components were now consolidated into a single menu strategically positioned on the user's left palm. This placement was chosen because of its optimal viewing distance from the eyes. There's a balance between the menu's proximity and its distance from the body. Users could access the menu whenever they wanted by turning their left palm upwards and doing a click action with their left thumb and index finger. The menu provided options like the checklist, mini-map, settings, and quit, in a sidebar next to the main content area. Figure 9 provides a good idea of how the selected feature from the sidebar expanded on the right, providing an enlarged view of the feature, similar to the layout of modern-day apps and websites. The menu had undergone a visual re-design, having a darker background and brighter borders, adhering to the brand style guide of the mining company, resulting in a more consistent, modern, and immersive appearance. These changes reduced user confusion, ensuring that interactive elements were intuitive and easy to access.

Figure 9: *Menu in phase 3: All interactive items are consolidated into a single menu on the user's left palm. The feature selected in the sidebar expands on the right. The checklist version has a new feature of the individual toggle label button, right beside the component name, that points to the location of the selected individual component.*

Based on the suggestions of stakeholders and subject matter experts, two new features were introduced to the checklist to upskill the recruits further. An individual component toggle button allowed users to quickly locate a specific component in that zone instead of locating all components, Figure 10. Another feature was that of component descriptions within each toggle label. Users can access and read the component's description by pressing the arrow button on the left side of the label to understand its function. This enhanced component learnability and information accessibility.

Changes had been made to the mini-map feature to streamline the teleportation process. To reduce the cognitive load, users could now directly click on their desired sub-zone in the zone button, with the laser. This eliminated the need to click the 'alphabet button' corresponding to the sub-zone. The visual cues, including labels and hover effects, aimed to enhance the overall user experience, ensuring ease, intuitiveness, and engagement. Positive feedback from subject matter experts during testing validated the effectiveness of the toggle labels feature.

SETTINGS

SOUND ☑

VOLUME

LANGUAGE Spanish

Loose Damaged Railing

The railing is loose.

Figure 10: *The image showcases the toggle label feature. This feature points to the location of the selected component. The latest addition to this feature gives information about the component and its working. It can be accessed by an arrow button on the left side of the toggle label. The image also shows the Spanish language feature made available to the users.*

Clicking on a Button

Whenever the Menu is open, you will notice a laser in your right hand. Point it to the desired 'click' location, then

1. Using Controllers, pull the Right Controller Trigger with your Index Finger in the back of the controller.

2. Using the HaptX Hand Gloves, Pinch using your Right Index and Thumb fingers making the hand gesture shown below.

Figure 11: *The tutorial level shown in the image acts as a guide and educates new users about interactive VR. It explains how to interact with the checklist, mini-map, and other settings such as interactive objects, and opening/closing the menu. The instance in the image is of users being given hands-on experience on the front-left wheel of the truck.*

To educate users about VR interactions and eliminate any external assistance, a tutorial session, shown in Fig 11, guided the users through VR interactions. This addition acted like a classroom session, from an actual training module that provided instructions and gave them control over their action in the VR. It ensured that the users were prepared and had a seamless overall experience during the main training module, especially for the non-tech-savvy people, i.e., 40 years and older, from the target audience. Users got practical hands-on practice with the front-left wheel from zone 1-D. In this phase, a Spanish language option was introduced, recognizing potential use in Latin American countries where English may not be prevalent. To broaden accessibility, users could now translate the entire experience into Spanish. This inclusivity minimized language barriers, expanded access to training for a diverse audience and fostered the development of proficient truck operators. The experience concluded with a knowledge assessment test mentioned in design phase 2.

4.5 Testing:

Testing and evaluation are important for validating the platform's functionality and efficiency. To achieve this, the team organized demo showcases after each design phase, inviting mining company experts to our lab for a firsthand experience of the project's progress. Figure 12 shows the stakeholders and truck operator trainers experiencing the training simulator using the VR headset and haptic gloves. While observing their interactions, the team noted any difficulties, frustrations, or discomfort encountered by the users during testing. Colleagues of the users often provided additional insights, questions, or suggestions, all of which were diligently noted for future reference.

After the demo showcases, the team, alongside stakeholders and truck operator experts, conducted a comprehensive post-test briefing, shown in Figure 13. Stakeholders shared feedback, suggestions, and concerns about the project. Specific questions were asked about their testing experience, such as how was the

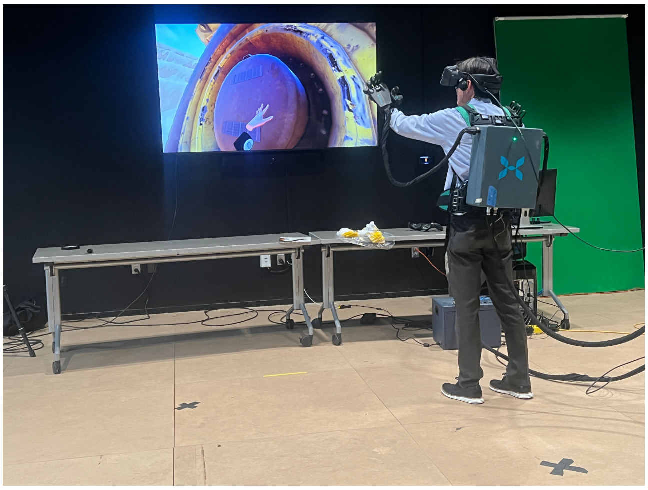

Figure 12: *The image is of one of our stakeholders experiencing tactile feedback on their hands during the usability testing session. These testing sessions gave us a chance to find out if our users were having any sort of discomfort or frustration due to the experience. The team members observed the participants and took note of points where there was scope for improvement.*

overall experience of the testing, what parts stood out in the experience, what parts you found frustrating or confusing, how would you rate the overall usability and user experience, what can we improve or add to the experience, how do you see yourself using these gloves and the technology in the future, what are the next steps you'd like to take for this project. Tailored follow-up questions were asked to extract in-depth information. This approach ensured the collection of practical insights to guide the project. The direct involvement of experts in the evaluation process facilitated honest feedback for effective refinement and enhancement.

5 Discussions and Insights

The project aimed to revolutionize the training modules in the mining industry. This enhancement used cutting-edge technology like Virtual Reality (VR), which specifically aimed to promote efficient and safe education for new truck operators on pre-op inspection. The project's ultimate goal was to reduce time and increase the efficiency of training new truck operators to get familiar with their vehicles.

After thorough testing and evaluation by the stakeholders, a unanimous agreement was reached that the project successfully replicated the pre-op inspection process for haul trucks. Stakeholders and subject matter experts emphasized that adopting this VR training platform would provide substantial advantages in training new recruits. Their feedback highlighted that the VR simulator encompassed all the essential elements necessary for conducting a pre-op inspection within a virtual environment.

In the third phase, a significant addition was made in the form of a tutorial session to guide users about VR interface interactions. This tutorial session

Figure 13: *Post-test briefing session, where stakeholders would express their views, feedback, and concerns about the pre-op inspection training simulator. It included our team asking them questions about their experience with the simulator followed by follow-up questions depending on their answers. These briefing sessions provided a good platform to understand the client's views and expectations from the product that we're developing.*

enhanced the user experience by making the simulator more easy, intuitive and accessible. Users enjoyed the freedom to move in any direction within designated zones and liked exploring areas of the truck that are physically inaccessible in the real world. The checklist proved invaluable for identifying components to inspect, and the use of haptic gloves, offering tactile feedback during interactions, greatly enhanced immersion, creating an engaging and memorable experience.

Critical decisions, such as consolidating the entire menu into the user's left palm, introducing an expand button for component descriptions, incorporating real-life interactions for increased realism, and maintaining a seamless user flow, significantly contributed to the overall user experience. Stakeholder and expert feedback included statements like "The project has effectively captured the size and scale of the trucks and machines," "Learning with all your senses," "This will help us keep people out of harm's way and yet find skilled individuals," and "A substantial measure of effectiveness between new and seasoned operators." These statements indicated the project's success in simulating VR pre-operational inspection training.

5.1 Insights:

Target Users The technology primarily caters to young individuals, however, it is crucial to acknowledge that a substantial number of the target audience, approximately 30-40%, falls in the "40 years and above" age group. Older users usually exhibit reluctance towards this innovative technology. During the testing phase, they struggled with VR interactions and occasionally experienced confusion or difficulties in navigating the virtual environment. External assistance was occasionally provided to help them navigate the simulation. As highlighted by one expert, "These individuals may require more time to accept this technology, and in some cases, they might express hesitation in adopting it."

User Behavior Gaining insights and understanding the user's behavior and background is very important before you design or develop any project. Specifically, for this project, it was important to acknowledge that individuals often change companies. This created a lack of familiarity with the new pre-operation inspection process, component nomenclature, and intricacies of a new company's haul truck. As Pizarro et al. (2021) [18] outlined in their study, it's important to acknowledge the diverse characteristics of the target audience, such as individuals having symptoms like anxiety, depression, stress, and mental fatigue. Furthermore, younger individuals tend to neglect reading shop manuals and operation and maintenance manuals, as they are hundreds or perhaps thousands of pages long. These factors emphasize the importance of considering these variables when designing any VR experience in the mining and construction industry.

Visual Design Users often faced challenges in identifying both the name and location of various components. This led to confusion and a waste of time while training. The introduction of component labels pointing to the component's location significantly improved the user's experience by reducing the time needed to locate specific components. A pivotal aspect of user interface (UI) design involves its dynamic nature, marked by automatic brightness adjustments based on lighting conditions, as well as resizing and angle adaptations tailored to the user's point of view and distance from the user. These dynamic UI features played a crucial role in helping users maintain their orientation without causing disruptions or readability issues. Engaging in VR training in the mining industry provides users with a tangible understanding of the size and scale inherent to mining operations and machinery. Hence it is important to design such a UI that feels like it is a part of the mine and doesn't stand out bold, enhancing the immersion in these environments.

Interaction Design Haptic gloves enhanced immersion and realism by enabling natural hand and body movements, fostering muscle memory for specific actions or tasks. However, designers must consider the gloves' bulkiness, which may lead to misjudgments of hand positions and unintentional clicks when interacting with buttons. Effective design communication, including hover effects, color changes on hover, sound feedback for actions, and clear map position indications, is crucial in preventing errors and instilling user confidence. Sun and Yuan [23] note in their research that students in VR exhibited higher levels of general, visual, and social fatigue, reducing confidence compared to regular conditions. The probable reason, as indicated, is the platform's unfamiliarity or prolonged headset use. It is highly encouraged to include interactions inspired by daily life activities, e.g., button clicking or pointing-and-clicking (laser-clicking) that are familiar and easy to use for the user.

Accessibility Instructions in the experience must be clear, concise, and universally understandable, catering to users of all ages and spoken languages. The incorporation of both visual and audio cues proved pivotal in helping users comprehend their situation and navigate challenges effectively. Visual cues, especially, played a crucial role in overcoming language barriers in the VR environment. Considering the demographics and the demanding nature of mining work, integrating ergonomic design principles is imperative to minimize physical strain, facilitate easy element identification, improve overall comfort, and ensure an intuitive user experience for miners. The introduction of the tutorial session substantially improved the product's accessibility by enhancing the overall smoothness and ease of the primary experience.

UI Considerations In Virtual Reality (VR), the user interface (UI) can occupy a significant portion of the user's field of view. Therefore, it is crucial to ensure an adaptable UI, allowing users to pull it up for reference or close it as needed. The UI should follow minimalistic design principles, highlighting only essential controls and features to prevent clutter from obstructing the user's view but, at the same time ensuring the UI is intuitive to avoid confusion and stress. Avoiding overwhelming the VR experience with extraneous information and complex UI is imperative as virtual hands can get stuck in the UI causing lag in the actual physical action and the system's response to the user. Another thing to consider, when using haptic gloves, people love to touch and press buttons to learn the interaction. This calls for the UI to be spacious enough to avoid accidental clicks and extreme physical movements.

6 Future Works:

VR has successfully overcome challenges like time, space, safety, and resource access, yet it grapples with technical limitations such as expensive hardware, high power consumption, the need for platform standardization, and portability challenges. Despite these limitations, the project excels in delivering precise pre-op inspection training. Addressing concerns from stakeholders and truck operator trainers, particularly enhancing haptic glove reliability and introducing edge cases for recruit training, will be crucial.

Current simulation scenes cover safety gear donning, truck exploration, and component inspection. Future iterations could include edge cases like risky rescues, drills for dangerous circumstances, and player injury simulations, significantly boosting training effectiveness. Exploring voice commands for task completion is a promising future development, simplifying interactions for users. Instead of clicking UI buttons, users could use voice commands to manipulate a holographic truck representation for teleportation and invoke component names to update the checklist automatically. Another possibility is having a virtual narrator in the scene to guide the user through the experience. Notably, a study found that a storyteller narrating a social situation is more effective for knowledge retention than enhancing VR scene fidelity [5].

The simulator aims to benefit the business by minimizing interruptions to on-site mining operations and streamlining inspections. Providing operators with a comprehensive understanding of what and where to inspect beforehand will reduce on-site errors, ultimately enhancing operator efficiency.

7 Conclusion

This paper introduces a virtual reality pre-op inspection training simulator, providing users with an efficient hands-on training experience, eliminating the need for traditional classroom instruction, manual reading, or exposure to extreme weather conditions. Our project equips recruits with cutting-edge VR technology, empowering them to effectively enhance their pre-op inspection skills. The implementation of VR technology enables the mining company to educate, train, and up-skill their workforce, ensuring the prepared and confident performance of pre-op inspections at the actual mine site. VR has significant potential to revolutionize education in the mining industry, offering cost-effective, time-efficient, and highly efficient training solutions compared to traditional methods. Furthermore, valuable insights have been shared that were gained from various stages of the design process throughout the project's duration. In conclusion, future directions for the project are outlined, exploring opportunities for expansion and enhancement to increase its impact and comprehensiveness.

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