

VIRTUAL REALITY TRAVERSE: A NOVEL WAY TO TEACH TRAVERSE SURVEYING

Lawrence Lau, Andy Mack, Wei Yao

Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University

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ABSTRACT:

With the advancement of technology, lowered cost in hardware and widely available development tools, more and more educators across different disciplines have used virtual reality as a mean to enhance their teaching. The hit of the pandemic has also speeded up the adoption of virtual reality in education where face-to-face classes and practicals are suspended/cancelled. Virtual Reality as a tool to facilitate teaching and learning has created a new way for learners to experience the materials instead of receiving information passively through books and videos. Traverse survey is one of the main topics in surveying, it is a method used for control survey through establishing a series of points that are linked together by straight lines to form a framework. Traversing involves setting a total station and prism targets at points along the traverse line to do observations. Measurements of angles and distances are taken for the calculation of the points' coordinates using trigonometry. This paper illustrates using freely available tools to develop a virtual reality program for doing traverse survey, the program is used in an assignment as a virtual fieldwork tool for students to learn traverse surveying at home and anywhere with a computer.

1. INTRODUCTION

1.1 Virtual Reality in Education

Virtual Reality (VR) is a system comprises of both hardware and software which recreates a 3D virtual environment in real time. It has two crucial characteristics, being immersive and interactive. Through VR, the user can both experience and interact with the environment or content at will. These unique characteristics open up a new world for educators to explore and experiment that was impossible before and students can be more engaged in learning. (Alhalabi, 2016) found VR has significant advantages in enhancing students' achievements in engineering subjects.

VR is great for both visualisation and simulation, it is mostly used along or a mix of the following lines:

- Access inaccessible places (time, location, and safety);
- Training that involves high cost/scarce resources or equipment;
- Training with safety concerns;
- Visualisation of designs, objects or concepts.

Other than some common uses of VR in education like flight simulation and virtual surgery, there are some other interesting examples. (Tai et al., 2022) uses VR in training car-detailing skills. It explores the relationship between self-efficacy, learning interest, learning anxiety, flow experience and learning retention through car-detailing tasks like wheel and rim cleaning, car cleaning, waxing, and wiping. (Doganyigit et al., 2022) uses VR in vocal training. It uses rollercoaster ride as a mean to help the user reach the high notes in difficult passage where they may use their own imagination otherwise. The VR helps them to achieve higher notes and better control of their voice. (Singleton et al., 2022) uses VR to teach nursing students how to treat diabetic patients. The VR program simulated a hospital wardroom with a deteriorating patient. The student has to study the knowledge about the patient's condition and hopefully can identify and treat when the patient later experiences hypoglycaemia. (McGovern et al., 2020) uses VR to improve business students' presentation skills. The VR simulates virtual environments with virtual audience to help users overcome fear in public speaking. The

program can provide instant feedback and scoring and can record presentations for playback.

VR can be divided into two different types. The Immersive type and the desktop-based type. Immersive VR requires specialised equipment, a VR headset and an input device, whereas desktop-based VR can use a conventional computer. Both types have their own advantages and disadvantages. The immersive type has a higher entry barrier as it requires specialised equipment, therefore, large-scale deployment is more difficult and expensive. Motion sickness and safety are also more of a concern for immersive VR. On the other hand, desktop-based VR being less immersive, is more accessible. However, a 2D monitor, mouse and keyboard are difficult to replicate what immersive VR offers. Being more immersive is not necessarily better in terms of teaching and learning, it all depends on the application. (Makransky et al., 2019) compared learning with the same simulation, one with immersive VR using VR headset and the other using desktop PC, found that immersive VR has higher cognitive load to users which users reported higher presence but learned less. (Albus et al., 2019) also found that presenting too much visual information may influence the learning outcome.

1.2 Motivation of VR for Teaching Surveying

Traverse surveying is a basic surveying skill that students must master in their surveying class. Traversing starts by setting a total station at a control point with known coordinates and measuring a target at a subsequent point along the traverse line; see a link traverse in Figure 1 (Schofield and Breach, 2007). With all the needed observations taken, the total station is then moved to the measured point to make observations, the procedure is repeated until the end of the traverse line is reached. VR is about virtual 3D environments, which is a great fit for teaching land surveying as it is about measuring the environment. One of the earliest attempts (Lee et al., 2000) using VR to simulate traversing uses 360-degree panoramic photo. The panning of panoramic photo on a computer screen is quite similar to what a total station does at one spot. Despite being photo-realistic, this approach has a big drawback as photos must be taken beforehand and points are pre-determined. This takes away the realism and freedom of the user. As technology matures, recent attempts of using VR in teaching surveying uses immersive VR, which is real 3D in contrast to

panoramic photos. Topics include levelling (Bolkas et al., 2021), topographic survey (Levin et al., 2020) and collaborative training experience on surveying equipment.

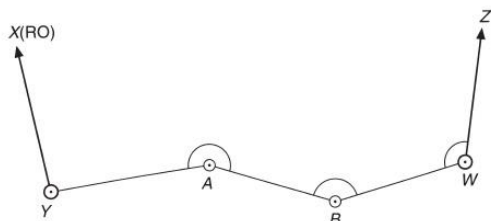


Figure 1. An example of a link traverse. (Schofield and Breach, 2007)

All surveying practicals and face-to-face lectures were abruptly forced to cease at the beginning of the Spring semester of 2020-21 due to the COVID-19 pandemic; students were asked to stay home and attend lectures online. Learning surveying without doing any actual fieldwork is far from ideal, in fact the Engineering Surveying subject in the department requires students to pass both practical and exam. To ease the situation, we decided to develop a VR traverse survey assignment for students to get a taste of real-world surveying. The subject in question has a total of more than 200 students with a mix of backgrounds. For the assignment, students are required to run a closed/link traverse from control point 1 to control point 2 with four or more new points in between of their own choice. Students have to use the VR Traverse program for the fieldwork. With that, they can do site reconnaissance to plan their own traverse line, set up instruments at locations of their choice and make observations. They need to book the measurements manually and complete the assignment by doing the computations and adjustments. The assignment is accounted for 10% of the subject.

2. DEVELOPMENT OF THE VR TRAVERSE TOOL

To deploy in such a large scale, desktop-based VR is the only choice as the VR Traverse program (see Figure 2) is meant for students to run at home with their own computer without any specialised equipment. Even without the deployment restriction, desktop-based VR is still more preferable for our application which is easier to learn and use. The VR Traverse program is created by using Unreal Engine 4. Unreal Engine is chosen for its cost, visual scripting capability, and HTML5 output. Unreal Engine is generally free to use and is one of the most popular game engines for game development. Visual scripting can greatly speed up the development time as changes can be made quickly, thus testing is much faster. Unreal Engine uses WebGL for HTML5 output, this option enables us to run our program as a fully cross-platform web-based program. The 3D assets of the program like the survey equipment, the buildings and the environment are all created in Blender. Blender is a free and open-source 3D software for 3D modelling and more. Thanks to the creators of both Unreal Engine and Blender, our VR traverse program is made possible by these powerful free tools.

The 3D environment of VR Traverse is created specifically for this assignment. It is a small enclosed environment with buildings that mimic buildings of The Hong Kong Polytechnic University to promote sense of belonging (see Figure 3). All the buildings and instruments are true to scale, pairing with a total station lens of correct magnification, there isn't much difference between surveying in VR and real world. Two control points are marked on the ground on two separate raised platforms, and two reference objects (ROs) are located at the exterior of two

buildings near the roof. Users can explore freely within the environment and set up instruments at any places they want with minimal restrictions. Just like actual fieldwork, the program is in a sense barebone, which enables users to complete the traverse in whatever way they want; the booking of measurements and computations are done manually outside of the program as in the actual practical counterpart.

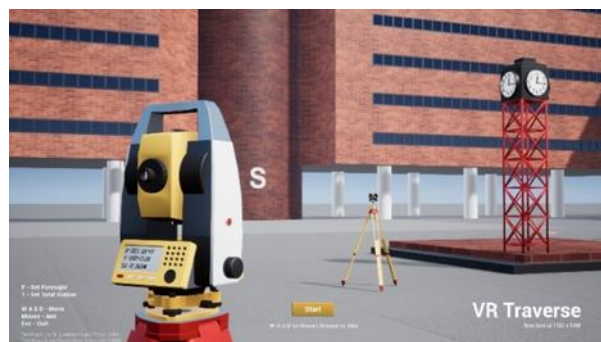


Figure 2. Start screen of VR Traverse

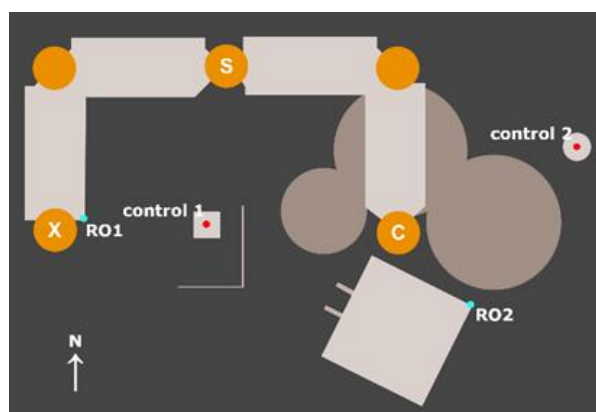


Figure 3. Map of the environment

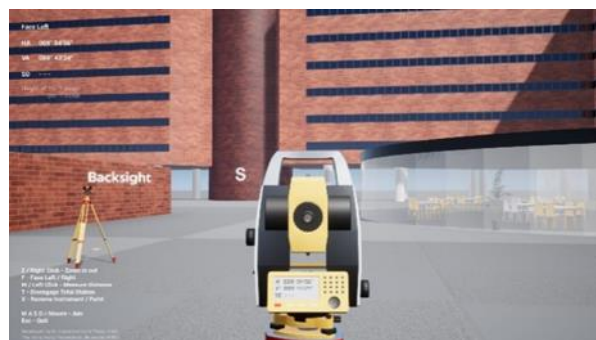


Figure 4. Total Station mode, available commands are shown on the lower left

There are basically two modes in the program, the surveyor mode and the total station mode (see Figure 4). The surveyor mode is for the user to walk around and to set up instruments, while the total station mode is for controlling the total station. All the commands, the user needs, are displayed on the lower left of the screen (see Figure 4), they will change according to their circumstances. i.e., in surveyor mode, commands for navigation and setting up of instruments are displayed while commands for operating the total station are displayed under total station mode.

To fully utilise the empty space of the virtual environment, a map and instructions are added to a wall (see Figure 5). After opening the program, users are advised to first go to the wall to study the map and instructions before beginning their task. The map has marked locations of the control points and reference objects. The added instructions are great how-to tips for students to complete the assignment.



Figure 5. Map and instructions are displayed on a wall

2.1 Design of Control stations

The user must first locate and set up the total station at control point 1 which is marked clearly on the ground (see Figure 6). VR Traverse isn't a program for training how to set up a total station, it is for teaching students how to run a traverse survey. Therefore, the setting up of the instrument is mostly done automatically by the program. Levelling of the total station at each point is not required, the location of the total station is final once it is set. Steps like grabbing and manoeuvring two tripod legs simultaneously or turning two foot-screws of the tribrach at the same time are hard to replicate through a computer screen with mouse and keyboard control. Immersive VR or touch screen is perhaps more suitable for such tasks. The user can choose to set up backsight, foresight, or total station by pressing their corresponding command key. Setting up any of these is the same. A bright circle is projected in front of the user onto the ground as a rough guide. In the case of setting up the total station, the user can first use the circle to encircle the control point and press T to invoke the total station setup. A semi-transparent total station along with a solid tripod will be shown for the user to get an idea of where the instrument will be set; For precise positioning, both laser plummet projected from the centre of the total station and optical plummet view on the lower right of the screen are provided (see Figure 6). Also, movement will be more refined during the process. After placing the crosshair of the optical plummet view to the centre of the control point, the user can left-click to set the total station. The program has collision detection where a warning will be shown when the instrument is set too close to a wall or other object. The total station will be levelled and centred, and the legs of the tripod will be extended to the ground. The tripod leg extension will work even on sloped ground where legs are extended to different lengths. The total station will be set at a random height every time within the range of eye level and the instrument height is displayed on the upper left. When the total station is set, the user will enter the total station mode directly, in which the user is in direct control of the instrument. To set up the foresight, the user has to disengage the total station and back to surveyor mode. Setting up the foresight is the same as setting up the total station. For foresight, a nail will be added to the ground, and it will be marked as point 1 (see Figure 7), subsequent points will be marked incrementally. Both backsight and foresight are labelled clearly above the prism (see

Figure 8) to differentiate from each other and to avoid confusion. To further enhance the ease of use, the prism target will be pointing to the user or the total station (if present) automatically. Removal of instruments and/or points are possible if, for any reason, the location isn't desirable.



Figure 6. Setting up of a total station at a control station



Figure 7. New points are marked on the ground

The total station is loosely based on a Leica total station. Once set up and in total station mode, it will display the horizontal and vertical angles continuously on its screen, just like a real total station. The data will also be replicated at the upper left corner. In the total station mode, the user can roughly point it to the target using the optical sight above the lens by mouse or keys. After rough pointing, the user can then zoom in and point to the target precisely. When zoomed in, the movement of the lens is more refined. The crosshair is set to 1 pixel thick at 1080P and the total station has an accuracy of 1 second at both horizontal and vertical angles. Distance measurement will only work when it is pointed to a prism and is up to 1mm accuracy. Upon measurement, the prism will light up, followed by audio feedback, the slope distance between the centre of the total station and the centre of the prism will then be calculated and displayed. As mentioned earlier, the control points are on raised platforms, this is to ensure students need to calculate the horizontal distance using slope distance and vertical angle, as well as for easy checking of the calculation and marking of the assignment. After finishing taking and booking all the necessary observations for one face, the user can change the face of the total station by pressing a key. The total station will then rotate 180 degrees horizontally, and the lens will flip and point forward. The current face will be indicated at the top left corner. A small random increment or decrement is added to the rotation, so the user needs to point the target again. Three rounds of observations at each point are needed for this assignment. When completed, the user can move forward to the next point. To simplify the process, a swapping function is added. By using that function, the total station will become the backsight, and the foresight will become the total station. This

speeds up the moving and setting up of instruments dramatically, the user just needs to set up a new foresight after each swap. As all the points are marked on the ground, the user has the option to move and set instruments up manually, but that may take considerable time. Moreover, they can revisit any point afterwards, but that must be done manually by setting up all the backsight, foresight and total station. The whole process is repeated until control point 2 is finally reached. Although it is designed with user-friendliness in mind at every stage, it may still sound fairly complicated and can be overwhelming to students. For that reason, we have created a demo video explaining the features of the program.



Figure 8. Targets are clearly labelled

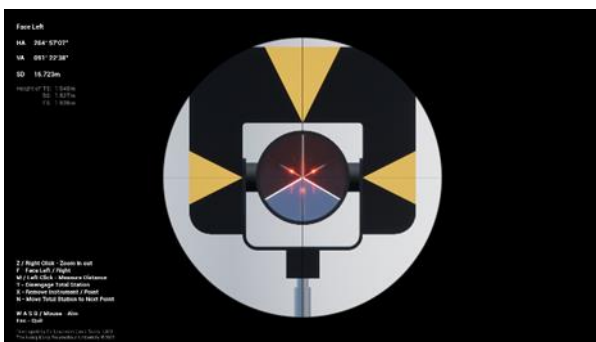


Figure 9. The prism will light up upon measuring

2.2 Surveying Accuracy and Errors

For the assignment, students are asked to redo the whole survey if the fractional linear misclosure is greater than 1:5000. From initial testing of the program, we found that the accuracy is extremely high. Of an approximately 200m traverse, the misclosure of Easting or Northing is often within 1mm or less, which is much higher than one may get from real-world surveying. This might be due to zero centring and levelling error of the instruments which are partially done by the program. Moreover, there is zero error in distance measurement no matter how far apart the instruments are as it is calculated by the game engine's coordinate system. And of course, the observations won't be affected by any environment and atmospheric conditions as in real life. This proves the game engine to be very capable of doing high precision work and is a great tool for developing virtual applications like this. However, as an assignment that includes fieldwork, computations, and adjustments, having extreme high accuracy or zero error isn't good, there isn't any error for students to adjust. To make it a more meaningful assignment, we need to introduce some errors to the system by changing the Easting of the control point 2, and the coordinates of the ROs several millimetres. Another factor that contributes to the minimal error is the thickness of the telescope's

crosshair. Such thin crosshair combining a high-resolution screen makes observations very precise and repeatable. The face left and face right difference in horizontal angle is often within one or two seconds. This is also not ideal as a fieldwork exercise, we want students to average out the difference between faces. Having a difference of one second leaves no room for averaging out. Therefore, a random number between one to five is generated at each point, we then add the random number of seconds to the horizontal angle of face left, and subtract that number from the horizontal angle of face right, making the face left reading is always +1 to +5 seconds and face right -1 to -5 seconds. By doing that, the difference between the two faces will be much greater, but that won't introduce any error to the traverse calculation as the differences are averaged out. Lastly, we have added a random error to the distance for students to do the averaging. A random $\pm 2\text{mm}$ distance error is added to each point, so for the distance of a traverse leg, the measurements from two different directions can differ up to 4mm (+2mm and -2mm), but that will be averaged out if that's the case. The maximum distance error for a traverse leg will be 2mm (+2mm +2mm, or -2mm -2mm) after averaging. In short, with both the changing of coordinates of the control point and ROs, and the adding of random distance error, bring up the misclosure of the Easting and Northing to several millimetres, making the accuracy of the traverse within 1:5000.

2.3 Computing Performance

The VR Traverse program is designed to run on PC natively with a monitor of 1920x1080 or better (if the GPU is powerful enough). Frame rate is a great concern as it may impact the usability of the program. Unlike running the program on lab computers, the program is meant for students to run at their homes, therefore, the biggest variable is the configuration of the students' computers which we are clueless. Having that in mind, we must ensure that the program can be run on a wide range of configurations without the need of a discrete GPU. To make that possible, the modelling of the 3D assets has to be very optimised, the less vertices the better as it will run smoother or faster given the same PC configuration. It is a balance between usability, fidelity and realism. Even with the limitations, we still modelled the total station and the prism target in great detail to give the user a sense of realism. For example, the prism is modelled from a cut-out corner of a cube with glass material applied which is geometrically and optically true to a real prism target. For the environment, we keep the buildings as geometrically simple as possible to lower the burden of the computer. Thirty frames per second (fps) is the bare minimum for computer action games. We have tested the program on a wide range of computers, those with a recent CPU can run the program at around 30fps or at least 20fps at 1080P. Among the computers we have tested, the one with the lowest specification, running an Intel Core m3-8100Y with Intel UHD Graphics 615, can run the program at 9fps at 1080P and 20fps at 720P. Despite being a little bit choppy, the program is surprisingly useable even at 9fps as surveying work is relatively static in contrast to an action-packed computer game. Unlike immersive VR which is usually developed with a chosen hardware in mind, we need to cater a wide range of screens as well. Displays of different resolutions and aspect ratios are taken into consideration when designing the user interface. The user interface is able to adapt for displays from 720P to 4k up and for different aspect ratios. However, we haven't tested whether a higher resolution display can improve the accuracy of the traverse. Other than the frame rate, we have to keep the file size minimal for easy distribution and installation. The final zipped package of the program is around 130MB.

2.4 Web version of the VR Traverse Tool

We learned that some students may use Mac as their computer, for that reason, we need to provide a viable option to those students without the need for them to come back to campus. Unreal Engine allows us to either recompile it as a Mac application (with a Mac computer) or as HTML5 web-based application (with version 4.23). It isn't without reason that there aren't many web-based 3D applications. First, it is not too practical or feasible to run a large program through browser. It is easy for 3D applications to get bigger than 1GB, many 3D games are often more than 100GB nowadays. WebGL, the 3D library that is supported by most browsers and used by Unreal Engine is quite dated, which means there are many limitations on the rendering. That is one of the reasons why Unreal Engine stopped supporting after version 4.23. On the other hand, the new web API, WebGPU looks very promising as it can harness the full power of the GPU. But WebGPU isn't supported by either Unreal Engine or Unity (another popular game engine) yet. Offering our program as web-based program has great advantage, as students can run the program anywhere through a browser without the restriction of platform and the need to download or install anything. Our project, which is considerably small and simple, WebGL should be more than adequate for such purpose. Converting the program to HTML5 is rather simple, we just need to use the correct version of the Unreal Engine right from the beginning. Due to the limitations of WebGL, the HTML5 version looks a bit different than the PC version, colours and lighting are muted. Small tweaks are applied to both lightings and materials to make the web version more appealing. The browser may also take control of the cursor sometimes, so extra messages are added to remind the user how to hide the cursor. Minor visual differences aside, both versions are more or less the same and HTML5 is proven to be very workable, and without further investigation, we only managed to make it work on chrome-based browsers. WebGL being a dated technology isn't without its merits, the sacrifice of visual fidelity results a much higher frame rate. The PC with lowest specifications mentioned earlier can now run at more than 30fps at 1080P (9fps non-web), which is more than three times faster than before. One caveat though, movement can appear blurry at times (due to the chosen heavy anti-aliasing), making the experience much less enjoyable. Students who had difficulty in running the program with their PC were asked to use the web version, which solved their problem.

3. STUDENT EVALUATION AND FEEDBACK

We asked the students two questions, “Problems you have encountered and solutions” and “What you have learnt through this VR practical” at the end of the assignment. Students found they have to be very careful in doing the assignment as there is no save and back function, one small mistake could lead to big misclousure down the line. This is in line with real-world surveying where there is no room for mistakes. Most students expressed that the VR Traverse is a great tool for learning surveying, especially during the pandemic where face-to-face practicals are not allowed. It helps them getting a way better understanding of the instrument and the surveying procedures than from books or videos. Some even wanted us to cover more topics using VR. They also pointed out VR has some practical advantages, it won't be affected by weather, and they can redo it as many times as they want without the time constraint of borrowing equipment plus without the fear of breaking them. A few students have spotted the discrepancies between the two faces and between the distance measurements from two directions, thought the program is inaccurate or malfunctioning. Little they know surveying in real life will have discrepancies also and that's the reason for taking multiple measurements. Some students want to have save and back function for them to go back to any point and redo, such functions are intentionally omitted to resemble real-world surveying. However, they can revisit any point by setting up the instruments manually as all points are marked on the ground. Apart from the two questions, we created a short anonymous survey for students as well. We asked them to rate from 0 to 10 (0-poor, 10-excellent) regarding the design and implementation of the program, as well as the usefulness of the software in helping their learning of practical surveying. For the three major questions, “Understanding of the instrument and operation”, “Understanding of the surveying procedures”, and “Overall Experience”, all have exactly 75% (of those completed the questionnaire) rated 6 or above, the distributions of ratings are different though (see Figures 10-12). We will have approximately 86% to 92% if counting 5 (neutral) or above. And for the ultimate question, “Does the VR training software help you learn the practical surveying?”, 87.5% of the students chose a promising “yes” (see Figure 13).

Understanding of the instrument and operation

72 responses

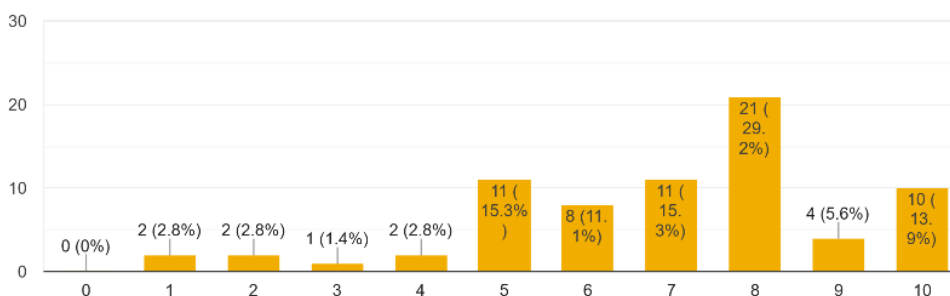


Figure 10. Evaluation results of understanding of the instrument and operation

Understanding of the surveying procedures

72 responses

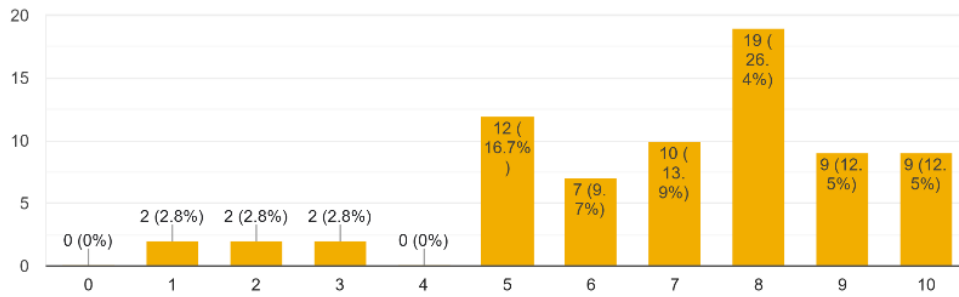


Figure 11. Evaluation results of understanding of the surveying procedures

Overall

72 responses

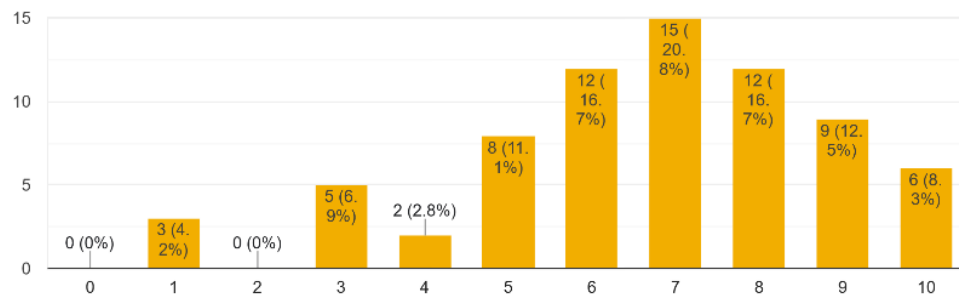


Figure 12. Evaluation results of the overall experience

Does the VR training software help you learn the practical surveying?

72 responses

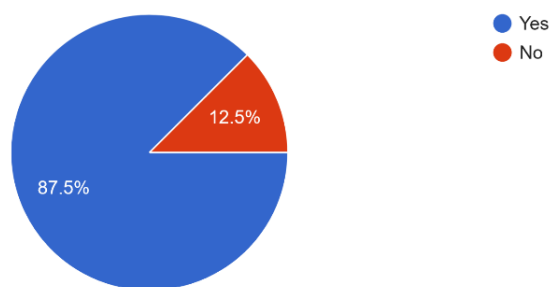


Figure 13. 87.5% of replied students think VR helps learning practical surveying

3.1 Possible Improvements

The VR Traverse was developed under a tight schedule, matters like assessment, calculation, data logging and export, human characters, manual focus, mini-map, more environments, multi-

player, and save can be implemented given ample time. The program works well as a virtual fieldwork tool for a simple traverse assignment, it can work equally well as a teaching tool for lectures. Teaching using VR is more illustrative compared to PowerPoint slides. Teachers can demonstrate surveying real-time in classroom and students can try it out alongside. With more

crucial topics covered, such as levelling, setting out and more, it has great potential to become a full-fledged teaching and learning tool for surveying. Even if labs are resumed, VR is a great tool to go hand in hand with real practical exercises. It gets students better prepared for practical in both surveying procedures and calculations.

4. CONCLUSION

With widely available free tools and advancement of technology, using VR for teaching and learning is well within reach nowadays. We illustrated using VR as a fieldwork tool for a traverse survey assignment. The VR Traverse program was developed using Unreal Engine and Blender, user can run a traverse by setting up total station and targets and taking measurements within it. It replaced the need of doing actual fieldwork and it gave students a trial of surveying during the pandemic when practicals were cancelled. The resulting program is highly accurate, we needed to introduce some errors for students to adjust because adjustment is crucial in surveying. Through assignment questions and an anonymous survey, we learned that the VR program was well received by students in which 87.5% of them thinks it helps them learn practical surveying. VR, when implemented fittingly, is proven to be a great and effective way for teaching and learning.

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