

ExcavatorVR - Simulating an Excavator in Virtual Reality

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Fig. 1: An outside view from the excavator after a quick playtest to dig out a smaller area

Abstract—This paper focusses on the design and implementation of a fully simulated excavator-driving environment for the Oculus Rift-S. The Goal was to simulate the controls of a real excavator as accurate as possible.

Index Terms—Virtual Reality, Machine Controls



1 INTRODUCTION

Over the years there have been many attempts and demos to try and create training and demo simulators for different kinds of jobs. Virtual Reality provides an irreplaceable opportunity to make the experience as realistic and easy to use as possible. Many different industries are already creating such software and distributing it, either for their customers or for their own employees.

Such software allows the users to train for the job in a safe space where the risk of accidents can be severely reduced whilst the economical and health dangers surrounding these are minimized.

During the conception of this project, the severe lack of training software for the construction industry in particular really stuck out. Therefore, in this context, the decision was made to create a small training simulator for excavator operators. Excavators have a comparatively high complexity for their controls and require a good intuition to use the machine effectively, which made this kind of vehicle the choice for this project.

2 USER GUIDE

This Project is designed to be played in a seated manner. The User is not supposed to change their position during the duration of the playsession. The Chair should be placed in the middle of the playspace and should face to the front of the configured playspace of the HMDs software.



Fig. 2: The View of the player during his VR experience

2.1 First Steps

After Startup the User is immediately placed into the drivers seat of their excavator. On the left and right console there is a grabbable joystick each and in front of the seat there are two levers.

The Controls of the excavator are based on the ISO Standard 10968. This Standard defines the following controls for the excavator:

- The left joystick tilting left causes the excavators upper body to swing left
- The left joystick tilting right causes the excavators upper body to swing right
- The left joystick tilting forward causes the excavators dipper, also known as stick boom, to move away. The Stick Boom of the excavator is the second half of the excavators arm, connecting the main boom with the bucket.
- The left joystick tilting backwards causes the excavators stick

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boom, to move closer.

- The right joystick tilting left causes the bucket of the excavator to curl in, therefore closing
- The right joystick tilting right causes the bucket of the excavator to curl out. Thereby allowing for the bucket to dump its contents
- The right joystick tilting forward causes the main boom and therefore the entire arm to go down
- The right joystick tilting backwards causes the main boom to go back up
- The left lever in front of the seat defines the movement of the left track of the excavator. The further it gets tilted, the faster the track moves. If it gets tilted backwards, the track moves backwards instead.
- The right lever in front of the seat defines the movement of the right track of the excavator. The further it gets tilted, the faster the track moves. If it gets tilted backwards, the track moves backwards instead.

Theoretically there is a second standard for the controls, SAE J1814, inverting the main and stick booms controls compared to ISO 10968, but for now the focus was put on the ISO standard.

The interaction is possible by hovering over the object to be controlled with a hand and then pressing the controllers grip button. For the Track-Levers the forward or Backward movement of the hand is translated into the lever moving forward or backwards. For the Joysticks a different methodology had to be found, due to the translation of 360° Movement into a translatable rotation proved more difficult than first expected. Therefore the behavior for the joysticks was made to relay the rotation movement of the hand to the joystick. Thanks for the joysticks being rather small this solution works quite well. The smaller size of the Joystick would make moving ones hand further away and still controlling the joystick rather unrealistic and unintuitive in comparison to the larger Track-Levers.

3 DESIGN

While a VR Project comes with a lot of weaknesses inherent to the nature of the current hardware, it also provides a lot of possibilities and strengths which are impossible to reproduce with other forms of media. The goal of this project was to use as many of the strengths whilst avoiding or mitigating the many pitfalls a lot of VR software is commonly affected by, such as motion sickness or high latency with the interactions

3.1 Keeping it simple

Freedom often leads to confusion. Therefore the goal was to streamline the user experience in a way, where the user is not overwhelmed and neither completely left to their own devices. This is managed through a few smaller systems and design decisions

3.2 Seated like in reality

Due to the focus being on simulating an excavator operators experience the decision was made to keep the user in the same location at all times. Whilst movement is still allowed, to enable the user to for example look out of the window of the vehicle, there is no incentive to leave the seated area.

This decision also avoids a lot of issues concerning motion sickness. Due to the user being in a seated position and the velocity of the excavator being rather slow by nature, moving with the excavator is not nausea inducing and should therefore make the simulation a lot more accessible to users with less to no experience with Virtual Reality.

3.3 The world confirms the excavators existence

One important aspect the simulation was of course the excavator buckets behavior. After all, getting a hang of the controls to move each component of an excavator effectively is only the beginning. Therefore it was essential to implement the most common task of excavators: The



Fig. 3: The View from the cabin after excavating a small hole and dumping material to create a small heap

movement of material through an area by digging it away and dumping it somewhere else.

Therefore it was important to make the shovel interact with the surrounding terrain of the excavator, allowing for it to create holes when digging and to dump material when opening the shovel over the terrain.

4 IMPLEMENTATION

4.1

The style automatically looks for image files with the correct extension (eps for regular L^AT_EX; pdf, png, and jpg for pdflAT_EX), in a set of given subfolders defined above using \graphicspath{ figures/, pictures/, images/}. It is thus sufficient to use \includegraphics{CypressView} (instead of \includegraphics{pictures/CypressView.jpg}). Figures should be in CMYK or Grey scale format, otherwise, colour shifting may occur during the printing process.

4.2 Vector figures

Vector graphics like svg, eps, pdf are best for charts and other figures with text or lines. They will look much nicer and crisper and any text in them will be more selectable, searchable, and accessible.

4.3 Raster figures

Of the raster graphics formats, screenshots of user interfaces and text, as well as line art, are better shown with png. jpg is better for photographs. Make sure all raster graphics are captured in high enough resolution so they look crisp and scale well.

4.4 Alt texts

Add alternative texts that describe the content of the image to all figures.

4.5 Figures on the first page

The teaser figure should only have the width of the abstract as the template enforces it. The use of figures other than the optional teaser is not permitted on the first page. Other figures should begin on the second page. Papers submitted with figures other than the optional teaser on the first page will be refused.

4.6 Subfigures

4.7 Figure Credits

In the **Figure Credits** section at the end of the paper, you should credit the original sources of any figures that were reproduced or modified. Include any license details necessary, as well as links to the original materials whenever possible. For credits to figures from academic papers, include a citation that is listed in the **References** section. An example is provided [below](#).

5 EQUATIONS AND TABLES

Equations can be added like so:

$$\sum_{j=1}^z j = \frac{z(z+1)}{2} \quad (1)$$

Tables, such as [Tab. 1](#) can also be included.

Table 1: VIS/VisWeek accepted/presented papers: 1990–2016.

year	Vis/SciVis	SciVis conf	InfoVis	VAST	VAST conf	TVCG @ VIS	CG&A @ VIS	VIS/VisWeek incl. TVCG/CG&A	VIS/VisWeek w/o TVCG/CG&A
2016	30		37	33	15	23	10	148	115
2015	33	9	38	33	14	17	15	159	127
2014	34		45	33	21	20		153	133
2013	31		38	32		20		121	101
2012	42		44	30		23		139	116
2011	49		44	26		20		139	119
2010	48		35	26				109	109
2009	54		37	26				117	117
2008	50		28	21				99	99
2007	56		27	24				107	107
2006	63		24	26				113	113
2005	88		31					119	119
2004	70		27					97	97
2003	74		29					103	103
2002	78		23					101	101
2001	74		22					96	96
2000	73		20					93	93
1999	69		19					88	88
1998	72		18					90	90
1997	72		16					88	88
1996	65		12					77	77
1995	56		18					74	74
1994	53							53	53
1993	55							55	55
1992	53							53	53
1991	50							50	50
1990	53							53	53
sum	1545	9	632	310	50	123	25	2694	2546

6 SUPPLEMENTAL MATERIAL INSTRUCTIONS

In support of transparent research practices and long-term open science goals, you are encouraged to make your supplemental materials available on a publicly-accessible repository. Please describe the available supplemental materials in the **Supplemental Materials** section. These details could include (1) what materials are available, (2) where they are hosted, and (3) any necessary omissions.

7 REFERENCES

An example of the reference formatting is provided in the **References** section at the end.

7.1 Include DOIs

All references which have a DOI should have it included in the bibTeX for the style to display. The DOI can be entered with or without the <https://doi.org/> prefix.

7.2 Narrow DOI option

The -narrow versions of the bibliography style use the font PTSansNarrow-TLF for typesetting the DOIs in a compact way. This font needs to be available on your LATEX system. It is part of the **paratype package**, and many distributions (such as MikTeX) have it automatically installed. If you do not have this package yet and want to use a -narrow bibliography style then use your LATEX system's package installer to add it. If this is not possible you can also revert to the respective bibliography styles without the -narrow in the file name. DVI-based processes to compile the template apparently cannot handle the different font so, by default, the template file uses the abbrv-doi bibliography style.

7.3 Disabling hyperlinks

To avoid adding hyperlinks to the references (the default) you can use \bibliographystyle{abbrv-doi} instead of \bibliographystyle{abbrv-doi-hyperref}. By default, the DOI field in a bibTeX entry is turned into a hyperlink.

See the examples in the bibTeX file and the bibliography at the end of this template.

7.4 Guidelines for bibTeX

- All bibliographic entries should be sorted alphabetically by the last name of the first author. This LATEX/bibTeX template takes care of this sorting automatically.
 - Merge multiple references into one; e.g., use [?, ?] (not [?] [?]). Within each set of multiple references, the references should be sorted in ascending order. This LATEX/bibTeX template takes care of both the merging and the sorting automatically.
 - Verify all data obtained from digital libraries, even ACM's DL and IEEE Xplore etc. are sometimes wrong or incomplete.
 - Do not trust bibliographic data from other services such as Mendeley.com, Google Scholar, or similar; these are even more likely to be incorrect or incomplete.
 - Articles in journal—items to include:
 - author names
 - title
 - journal name
 - year
 - volume
 - number
 - month of publication as variable name (i.e., {jan} for January, etc.; month ranges using {jan #{/}# feb} or {jan #{--}# feb})
 - series. E.g., “TVCG”, “TVCG/VIS” for special issue VIS papers, “EuroVis”, “CGF/EuroVis”.
 - Use journal names in proper style: correct: “IEEE Transactions on Visualization and Computer Graphics”, incorrect: “Visualization and Computer Graphics, IEEE Transactions on”
 - Papers in proceedings—items to include:
 - author names
 - title
 - abbreviated proceedings name: e.g., “Proc.\ CONF_ACRONYM” without the year; example: “Proc.\ CHI”, “Proc.\ 3DUI”, “Proc.\ Eurographics”, “Proc.\ EuroVis”
 - year
 - series. E.g., “VIS” and “EuroVis” for short papers, “CHI”...
 - Article/paper title convention: refrain from using curly brackets, except for acronyms/proper names/words following dashes/question marks etc.; example:
- The paper “Marching Cubes: A High Resolution 3D Surface Construction Algorithm” should be entered as “{M}arching {C}ubes: A High Resolution {3D} Surface Construction Algorithm” or “{M}arching {C}ubes: A high resolution {3D} surface construction algorithm”. It will then be typeset as “Marching Cubes: A high resolution 3D surface construction algorithm”.
- For all entries:
 - DOI can be entered in the DOI field as plain DOI number or as DOI url.

- “pages” or “articleno”: Provide full page ranges AA--BB, OR, if an article number is available like recent ACM conferences, use that instead. E.g., see the entry for Panavas et al. [?].
- When citing references, do not use the reference as a sentence object; e.g., wrong: “In [?] the authors describe ...”, correct: “Lorensen and Cline [?] describe ...”

8 APPENDICES

Appendices can be specified using `\appendix`. For example, our Troubleshooting instructions in Sec. B.

Note that the paper submission has to end after the **References** section and within the page limit of the conference you are submitting to. Any version of Appendices or the paper with Appendices included has to be submitted separately as supplementary material. You can use the `hideappendix` class option to remove everything after `\appendix`. We encourage you to submit a full version of your paper to a preprint server with any appendices included.

You can use the `\iflabelexists` macro to cross reference an appendix from the main text, but only if that label (i.e. the appendix) actually exists. For example, above we use

```
\iflabelexists{appendix:troubleshooting}
{\cref{appendix:troubleshooting}}
{the appendix of the full paper at
 \url{https://osf.io/XXXXX}}.
```

in order to cross-reference to the appendix with `\cref` if it exists, but if the appendix is commented out then we will simply create a hyperlinked URL to it.

9 FILLER TEXT TO FLUSH OUT THE PAPER

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

SUPPLEMENTAL MATERIALS

Refer to the instructions for this section (Sec. 6). Below is an example you can follow that includes the actual supplemental material for this template:

All supplemental materials are available on OSF at <https://doi.org/10.17605/OSF.IO/2NBSG>, released under a CC BY 4.0 license. In particular, they include (1) Excel files containing the data for and analyses for creating Tab. 1 and ??, (2) figure images in multiple formats, and (3) a full version of this paper with all appendices. Our other code is intellectual property of a corporation—Starbucks Research—and there is no feasible way to share it publicly.

FIGURE CREDITS

Refer to the instructions for this section (Sec. 4.7). Here are the actual figure credits for this template:

Figure 1 image credit: Scott Miller / Special to the Vancouver Sun, January 22, 2009, page A6.

?? is a partial recreation of Fig. 1 from [?], which is in the public domain.

ACKNOWLEDGMENTS

The authors wish to thank A, B, and C. This work was supported in part by a grant from XYZ (# 12345-67890).

A ABOUT APPENDICES

Refer to Sec. 8 for instructions regarding appendices.

B TROUBLESHOOTING

B.1 ifpdf error

If you receive compilation errors along the lines of Package `ifpdf` Error: Name clash, `\ifpdf` is already defined then please add a new line `\let\ifpdf\relax` right after the `\documentclass[journal]{vgtc}` call. Note that your error is due to packages you use that define `\ifpdf` which is obsolete (the result is that `\ifpdf` is defined twice); these packages should be changed to use `ifpdf` package instead.

B.2 pdfendlink error

Occasionally (for some L^AT_EX distributions) this hyper-linked bibT_EX style may lead to **compilation errors** (`pdfendlink` ended up in different nesting level ...) if a reference entry is broken across two pages (due to a bug in `hyperref`). In this case, make sure you have the latest version of the `hyperref` package (i.e. update your L^AT_EX installation/packages) or, alternatively, revert back to `\bibliographystyle{abbrv-doi}` (at the expense of removing hyperlinks from the bibliography) and try `\bibliographystyle{abbrv-doi-hyperref}` again after some more editing.