Effects of Object Complexity in Occlusion, Structure, and Texture on 3D Virtual Object Observation in Virtual Reality

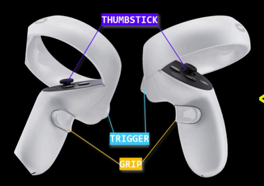
We present an empirical study based on the direct manipulation technique to evaluate the effects of various levels of object complexity in occlusion, structure, and texture on the observation of 3D virtual objects. A significant linear correlation between users' perceived optimal size and distance for direct manipulation in VR.

Background

Why focus on the effect of 3D virtual object?

- 3D virtual object observation plays an important role in Virtual Reality (VR) application areas, such as product design and museum.
- The virtual objects that users interact with are often of various complexity in occlusion, structure, texture, and sizes.
- The direct manipulation technique that most users are familiar with. It allows users to grab, move, rotate, and scale virtual objects

Interaction Technique



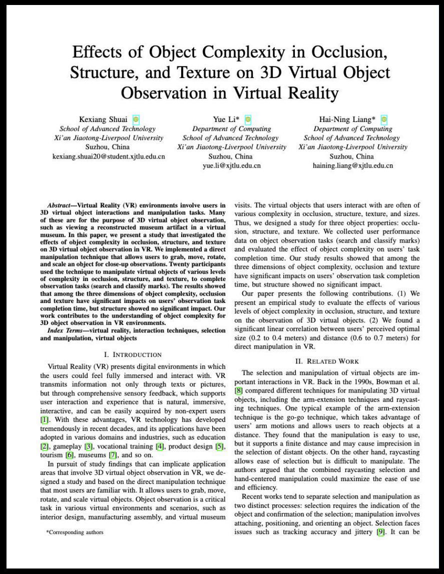
Virtual hands=Grabview

To Grab, press either grip button and press the trigger button to grab the captured object.

Ray-casting metaphors =Hoverview

To Move, hold the left trigger button, move the thumbstick to move the object along the ray.

Paper collection



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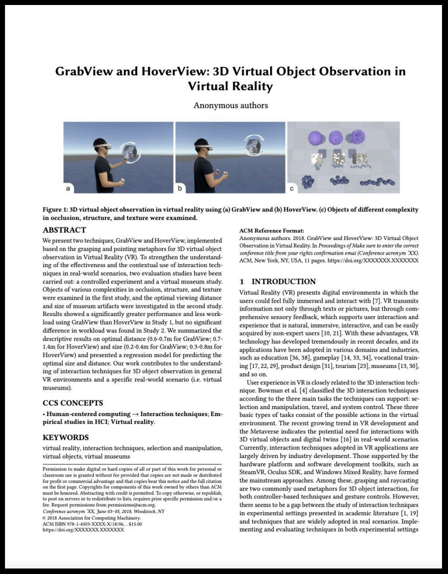

GrabView and HoverView: 3D Virtual Object Observation in Virtual Reality

Anonymous authors

Figure 1: 3D virtual object observation in virtual reality using (a) GrabView and (b) HoverView. (c) Objects of different complexity in occlusion, structure, and texture were examined.

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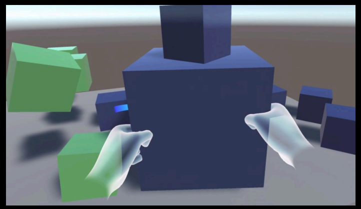
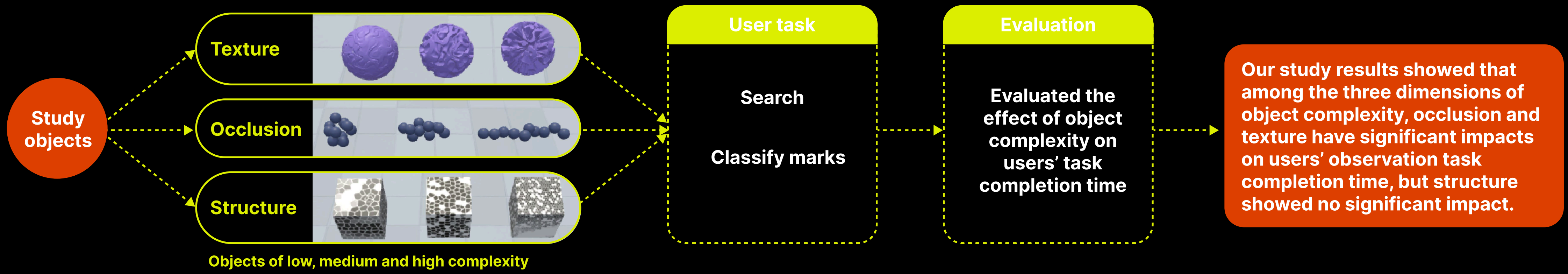
Paper Contributions

Paper intro



In pursuit of study findings that can implicate application areas that involve 3D virtual object observation in VR, we designed a study and based on the direct manipulation technique that most users are familiar with. It allows users to grab, move, rotate, and scale virtual objects. Object observation is a critical task in various virtual environments and scenarios, such as interior design, manufacturing assembly, and virtual museum visits. The virtual objects that users interact with are often of various complexity in ***occlusion, structure, texture, and sizes***.

Study process



Our contribution

We compared a grasping technique (i.e. GrabView) and a pointing technique (i.e. HoverView) for 3D virtual object observation in VR, and present an empirical study with various levels of object complexity in occlusion, structure, and texture.

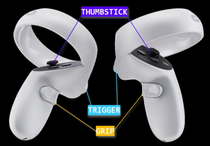
we also evaluated the techniques in a real scenario (i.e. a virtual museum) and discussed the different results in the two studies.

We collected user-identified data about the optimal viewing distance and size, and modeled their relationship. The results can be directly adopted and applied in the future design of virtual museums and implicate the interaction design in other scenarios.

Based on the results and findings, we discuss a set of design guidelines about interaction techniques for 3D virtual object observation.

Experiment Design

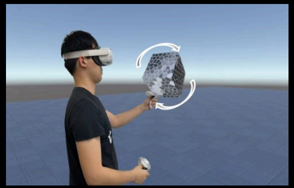
Experiment intro



We built the prototype system and implemented the technique using Unity (version 2019.2.0f1) on a computer with a Core i7-9750H CPU @ 2.60GHz, 8GB RAM, and NVIDIA GeForce GTX 300 graphics card with 8GB RAM. The VR system was developed based on the SteamVR package, which is available in the Unity Asset Store and supported on most mainstream VR headsets. Our system was deployed on the Meta Quest 2 VR HMD, with a 1920 × 1832 resolution for each eye and a 72 Hz refresh rate. Interaction techniques were based on the two hand-held controllers. ***We set up C# scripts to record user interaction data and exported them to CSV files for further analysis***.

Implemented Techniques

We implemented a direct manipulation technique and realized three basic functions:



1. **Allowing users to grab an object at a distance**
2. **Change the object's position and orientation**
3. **Scale the size of the object**

The technique is based on the grasping metaphor and the virtual hand manipulation. We simplified the selection process in the techniques as we focus on the object observation task, which is more concerned with manipulation, namely, moving, rotating, and scaling an object to obtain an overview and delve into the details. To grab a remote object, the user needs to keep pressing the GRIP button of either controller to activate the magnetic function, and then press the TRIGGER button to grab the object.

Research questions

RQ1 Does virtual object complexity in occlusion affect observation efficiency in VR?

RQ2 Does virtual object complexity in structure affect observation efficiency in VR?

RQ3 Does virtual object complexity in texture affect observation efficiency in VR?

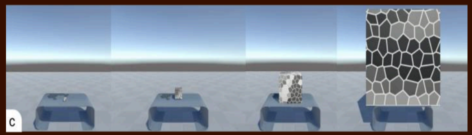
RQ4 What is the optimal size and distance for virtual object observation in VR?

Experimental environments and observation tasks

We implemented an experimental environment for observation tasks.

Experimental environment setup

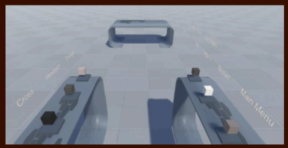
Three dimensions of virtual objects complexity: Texture, Occlusion, and Structure



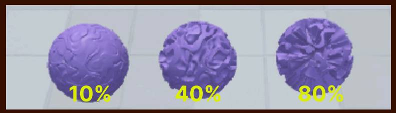
Different sizes of objects in the sample session

Study 1-Techniques and Object Complexity

Study 1 aims to answer RQ1 and examine the effects of two techniques on user performance. Participants need to ***complete object observation and classification tasks***.



Specifically, we examined three typical properties of virtual objects: occlusion, structure and texture.



Occlusion simulation

Structure simulation

Texture simulation

Study 2-Techniques in the Virtual Museum

To answer RQ2 and RQ3, we designed a study in a virtual museum environment and evaluate users' perceived workload using the two techniques.

Recording the optimal distance and size for each of the artifact observations, subjectively identified by the participants.

Study Procedure

Study intro

Participants were instructed to enter a tutorial scene to familiarize themselves with the direct manipulation technique, as well as the layout and system controls in the experimental scene. There are 9 sessions (***3 Complexity Dimensions × 3 Complexity Levels***) in total. We applied a randomized design for the experimental sessions to avoid the influence of the experimental order on the results. Each session had 4 trials of different object size. ***Participants were asked to scale the object, confirm the best viewing size and distance, and search the mark on the object***. Once participants completed the nine sessions, they were invited to attend a short interview to provide their comments. ***This study was conducted in a 2m × 2m space***, where participants were seated on a chair. The whole study lasted for ~25 minutes on average including the tutorial session (~5 minutes).

Participants

Twenty participants (12 males, 8 females) aged between 18 and 25 voluntarily took part in this study.

Information of Participant VR experience

5 Five of the participants have ***never used VR***

9 Nine participants' total VR ***use time is under 10 hours***

6 Six of them use the VR system frequently, ***with a total VR us time above 40 hours***

20 All participants have prior ***experience in 3D graphics***

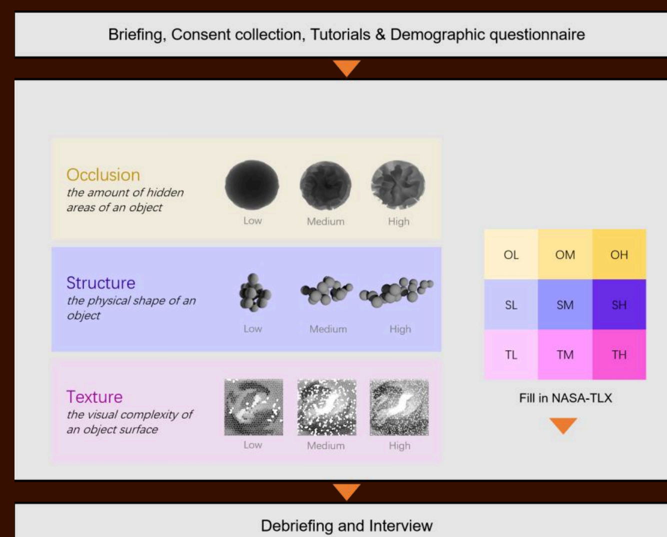
e.g., 3D games or 3D modeling software.

They reported an average of 3.38 (SD = 1.39) for VR familiarity and an average of 3.75 (SD = 1.01) for 3D graphics familiarity (5 = extremely familiar).

Procedure and Tasks

Study 1-Techniques and Object Complexity

There are 18 sessions (2 Techniques × 3 Object Properties × 3 Complexity Levels) for Study 1 in total (see Figure 8). To avoid the influence of the experimental order on the results, we applied a randomized design for the experimental sessions.



Participants were asked to randomly select from the 18 cubes set up in the main menu scene to start an experimental session. Each cube embodies an experimental session. Within an experimental session, there are 4 trials of different object sizes: 0.1, 0.3, 0.9, and 2.7 meters.

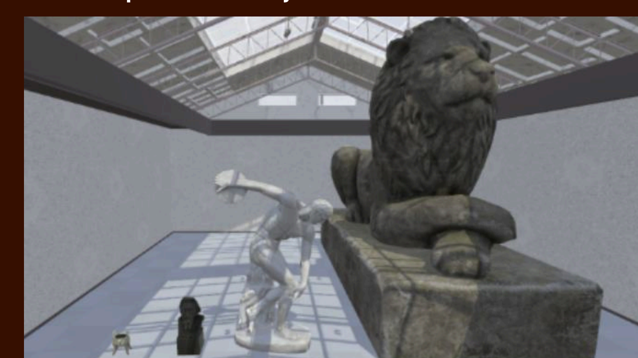
*Study 1 lasted for ~45 minutes on average including the tutorial sessions (~10minutes)

Study 2-Techniques in the Virtual Museum

Participants explored the virtual museum and interacted with the virtual artifacts freely without a time limit. When interacting with virtual artifacts, we asked participants to confirm a setting by pressing the X button on the left controller when they find the viewing distance and size of the artifact was optimal.

The virtual museum scene with preset teleportation points

The example museum objects of different sizes



*This study lasted for ~15 minutes on average

Study Results

Measures

Objective data

Study 1

- Categorization accuracy (18 in total)
- Task completion time (72 in total)

Evaluation formula: $A = S/T$

S = the number of successful trials

T = the number of total trials

Study 2

- Optimal distance
- Size for artifact

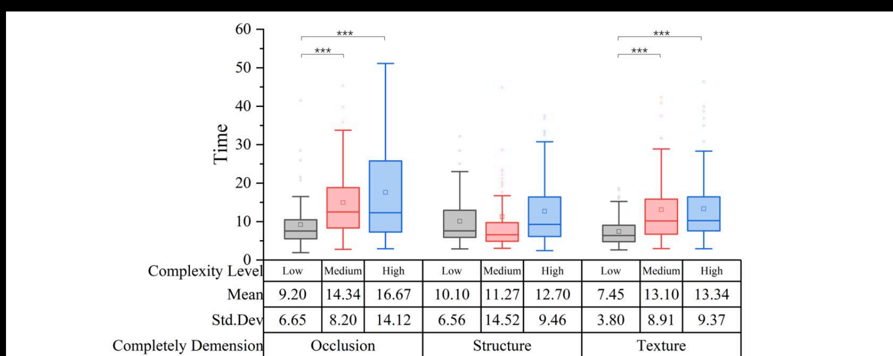
Subjective data

In both Study 1 and Study 2, we used the NASA-Task Load Index (NASA-TLX) to evaluate workload from six dimensions:

NASA-Task Load Index

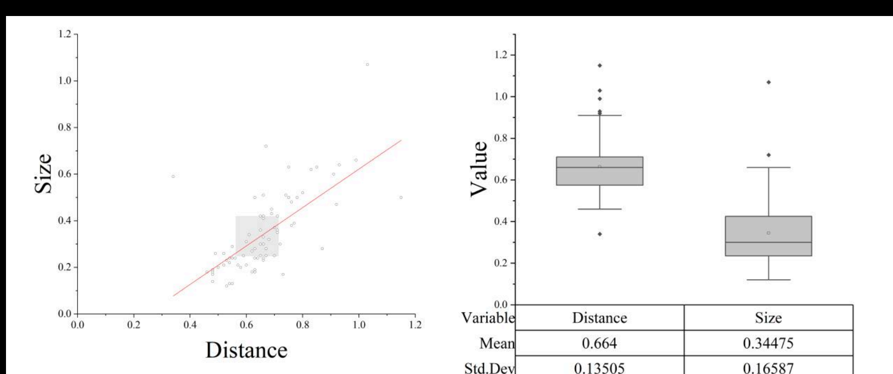
- Mental demand → Performance
- Physical demand → Effort
- Temporal demand → Frustration

Results



Complexity Level	Low	Medium	High	Low	Medium	High	Low	Medium	High
Mean	9.20	14.34	16.67	10.10	11.27	12.70	7.45	13.10	13.34
Std.Dev	6.65	8.20	14.12	6.56	14.52	9.46	3.80	8.91	9.37
Completely Demension	Occlusion			Structure			Texture		

*IBM SPSS Statistics



Variable	Distance	Size
Mean	0.664	0.34475
Std.Dev	0.13505	0.16587

*IBM SPSS Statistics

The categorization accuracy——100% for all participants.

The task completion time

- Occlusion (RQ1) has a significant impact on users' observation task completion time.
- Structure (RQ2) has no significant impact.
- Texture (RQ3) has a significant impact on users' observation task completion time.

The result also shows a significant linear correlation between users' perceived optimal size and distance.

0.2-0.4 Optimal size

0.6-0.7 Optimal distance

Insights

Disassembly

Observe the VR operation of complex machines and suggest disassembly tasks & objects to improve efficiency and experience

Focus point

When operating objects with complex materials, it is necessary to give users a "focus point" to facilitate precise operation.

User Scenario

Virtual museum application

The texture complexity of objects also had a significant effect on the efficiency of the observation tasks. A growing body of VR systems are designed for sectors that contain objects of various textures, such as interior design, museums and exhibitions, and the fashion industry.

The free exploration in the virtual museum does not require users to perform any specific tasks or set any time limits, which could have made the participants feel relaxed and decreased the psychological tension for both techniques.

These VR systems should consider improving the design for observing objects with complex textures, such as ***providing additional visual cues to direct users' attention towards a point of interest***.

The inscriptions serve as a storyline to guide users through the museum.

Disassembly observation

If observing complex objects, such as a phoenix crown, users can disassemble them for easier observation and a better interactive experience.

Disassembly

Magnify details

Reflection & Future Plan

Reflection

There are some limitations in this study:

- **Sample limitation**

  Our sample consists of a mix of novice and experienced VR users. The learnability of a technique has had an impact on the results.

- **Limitation in shape study**

  We found that participants made very few comments about the texture complexity. Comments on the texture session trials mainly revealed findings about the shape (i.e. cube). This probably indicates that for object manipulation, the effect of the shape and physical structure is more significant than the effect of the texture. This brings us to reflect on the occlusion session trials, where a sphere object was used to control the complexity degree. Participants found a lack of visual feedback in the rotation due to the evenly distributed shape, which may have disadvantaged HoverView in the evaluation.

- **Insufficient observation records**

  The interview with participants suggested a possibl relationship between the prior experience with joystick control and the experience with HoverView, given that the joysticks and controller buttons mediate both. We did observe significant individual differences in users with no game experience and those who reported to be experienced in both gamepad control and VR. However, we did not record users' familiarity with the joystick, so no inference can be made.

Future plan

- ***It is worth testing other interaction techniques in VR, such as ray-casting, HOMER, as well as indirect manipulation techniques, which may lead completely different result.***

- ***Quantify the complexity level and identify the benchmarks in order to inform more explicit design decision.***

- ***Studying user observation of real-world objects may yield new findings.***