




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

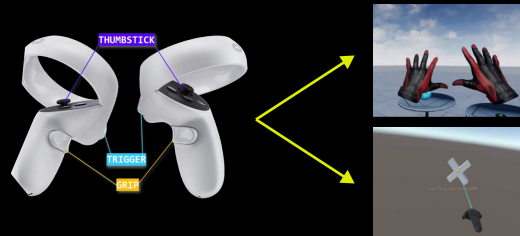
We present an empirical study based on the direct manipulation technique to evaluate the effects of various levels of object complexity in occlusion, structure, and texture on the observation of 3D virtual objects. A significant linear correlation between users' perceived optimal size and distance for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

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

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Abstract—Virtual Reality (VR) environments involve users in 3D virtual object observation and manipulation tasks. Many of these are for the purpose of 3D virtual object observation, such as viewing a reconstructed museum exhibit in a virtual museum. In this paper, we present a study that investigated the effects of object complexity in occlusion, structure, and texture on 3D virtual object observation in VR. We implemented a direct manipulation technique that allows users to grab, move, rotate, and scale an object for close-up observation. Twenty participants used the technique to manipulate virtual objects of various levels of complexity in occlusion, structure, and texture, to complete observation tasks (search and classify marks). The results showed that among the three dimensions of object complexity, occlusion and texture have significant impact on users' observation task completion time. Our study results showed that among the three dimensions of object complexity, occlusion and texture have significant impact on users' observation task completion time, but structure showed no significant impact. Our paper presents the following contributions: (1) We present an empirical study to evaluate the effects of various levels of object complexity in occlusion, structure, and texture on the observation of 3D virtual objects; (2) We found a significant linear correlation between users' perceived optimal size (0.2 to 0.4 meters) and distance (0.6 to 0.7 meters) for direct manipulation in VR.

Index Terms—virtual reality, interaction techniques, selection and manipulation, virtual objects

I. INTRODUCTION

Virtual Reality (VR) presents digital environments in which the users could feel fully immersed and interact with VR transmits information not only through text or pictures, but through comprehensive sensory feedback, which supports user interaction and experience that is natural, immersive, interactive, and can be easily acquired by non-expert users [1]. With these advantages, VR technology has developed tremendously in recent decades, and its applications have been adopted in various domains and industries, such as education [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40], [41], [42], [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53], [54], [55], [56], [57], [58], [59], [60], [61], [62], [63], [64], [65], [66], [67], [68], [69], [70], [71], [72], [73], [74], [75], [76], [77], [78], [79], [80], [81], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100].

II. RELATED WORK

The selection and manipulation of virtual objects are important interactions in VR. Back in the 1960s, Bowman et al. [1] compared different techniques for manipulating 3D virtual objects, including the arm-extension techniques and ray-casting techniques. One typical example of the arm-extension technique is the grab technique, which takes advantage of users' arm motions and allows users to reach objects at a distance. They found that the manipulation is easy to use, but it supports a finite distance and may cause immersion in the selection of distant objects. On the other hand, ray-casting allows ease of selection but is difficult to manipulate. The authors argued that the combined ray-casting selection and hand-centered manipulation could maximize the ease of use and efficiency.

Recent works tend to separate selection and manipulation as two distinct processes: selection requires the indication of the object and confirmation of the selection, manipulation involves attaching, positioning, and orienting an object. Selection faces issues such as tracking accuracy and jitter [2]. It can be

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

Anonymous authors

Abstract

We present two techniques, GrabView and HoverView, implemented based on the grasping and pointing metaphors for 3D virtual object observation in Virtual Reality (VR). To strengthen the understanding of the effectiveness and the contextual use of interaction techniques in real-world scenarios, two evaluation studies have been carried out: a controlled experiment and a virtual museum study. Objects of various complexity in occlusion, structure, and texture were examined in the first study, and the optimal viewing distance and size of museum artifacts were investigated in the second study. Results showed a significantly greater performance and less workload using GrabView than HoverView in Study 1. Not a significant difference in workload was found in Study 2. We summarized the descriptive results on optimal distance (0.6-0.7m for GrabView; 0.7-1.0m for HoverView) and size (0.2-0.4m for GrabView; 0.3-0.5m for HoverView) and presented a regression model for predicting the optimal size and distance. Our work contributes to the understanding of interaction techniques for 3D object observation in general VR environments and a specific real-world scenario (i.e. virtual museum).

CCS CONCEPTS

• Human-centered computing → Interaction techniques; Empirical studies in HCI; Virtual reality.

KEYWORDS

Virtual reality; interaction techniques; selection and manipulation; virtual objects; virtual museums

1. INTRODUCTION

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II. RELATED WORK

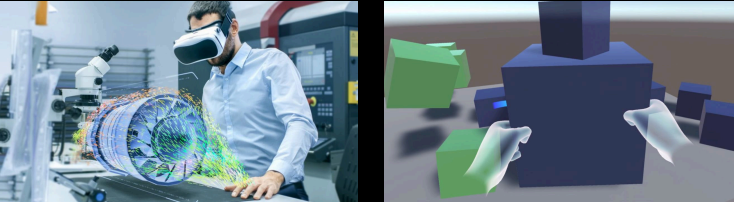
The selection and manipulation of virtual objects are important interactions in VR. Back in the 1960s, Bowman et al. [1] compared different techniques for manipulating 3D virtual objects, including the arm-extension techniques and ray-casting techniques. One typical example of the arm-extension technique is the grab technique, which takes advantage of users' arm motions and allows users to reach objects at a distance. They found that the manipulation is easy to use, but it supports a finite distance and may cause immersion in the selection of distant objects. On the other hand, ray-casting allows ease of selection but is difficult to manipulate. The authors argued that the combined ray-casting selection and hand-centered manipulation could maximize the ease of use and efficiency.

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<https://dl.acm.org/doi/10.1145/3544549.3583837>

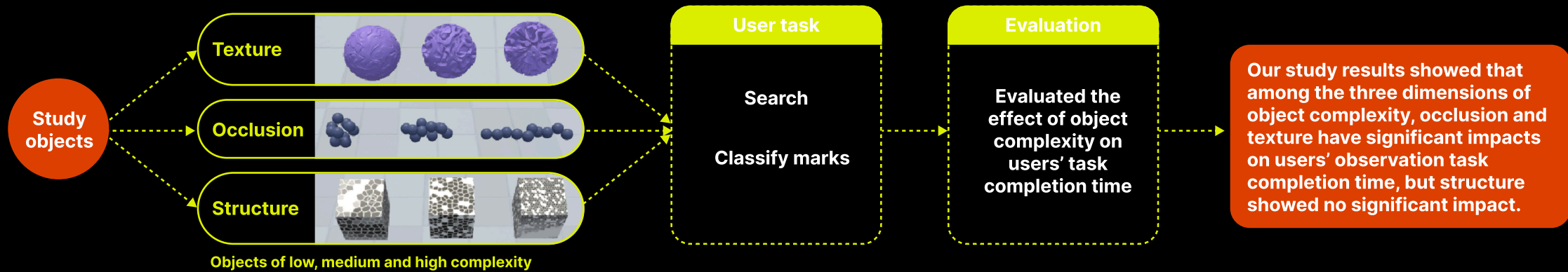
Paper Contributions

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.

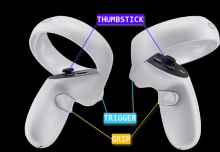
we also evaluated the techniques in a real scenario (i.e. a virtual museum) and discussed the different results in the two studies.

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

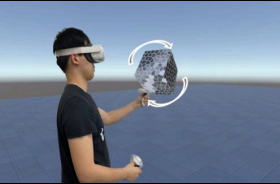
Experiment intro



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

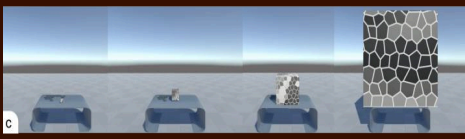
We implemented an experimental environment for observation tasks.



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

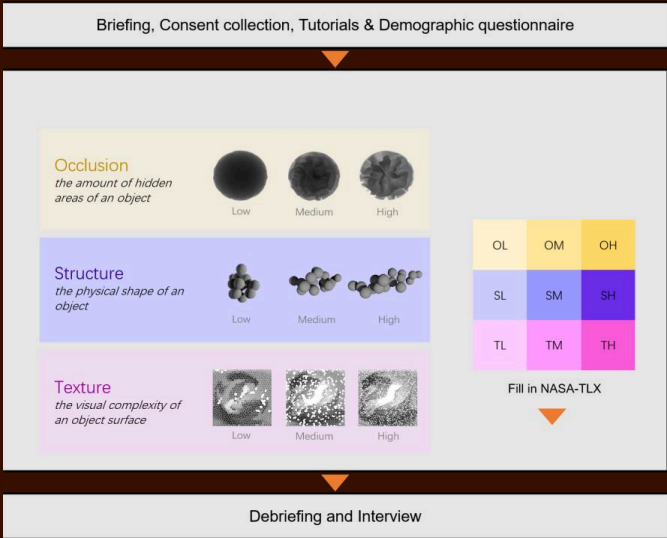
All participants have prior **experience in 3D graphics**
e.g., 3D games or 3D modeling software.

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)

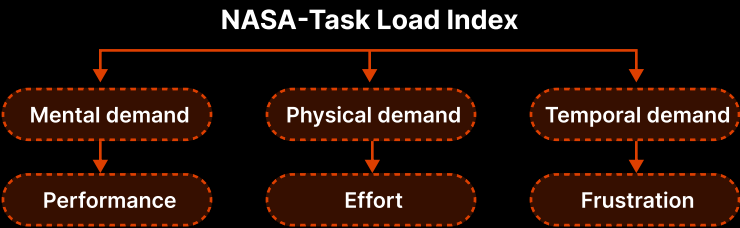
Evaluation formula: $A = S/T$ S = the number of successful trials
T = the number of total trials

Study 2 ●----->

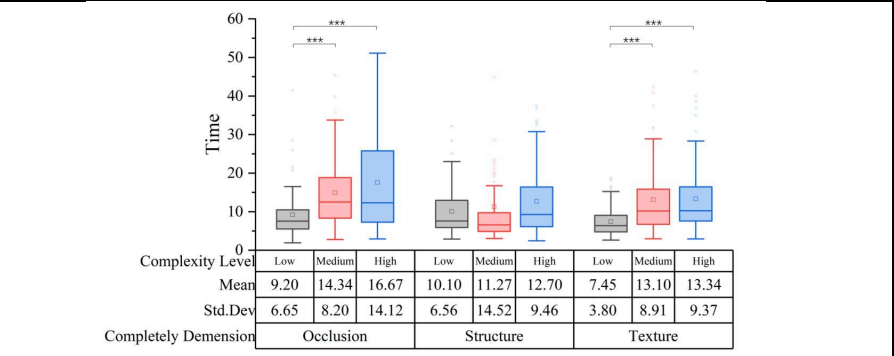
- Optimal distance
- Size for artifact

Subjective data

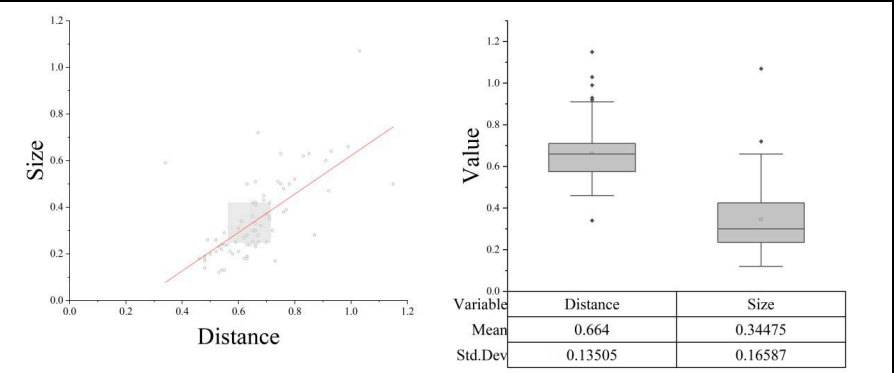
In both Study 1 and Study 2, we used the NASA-Task Load Index (NASA-TLX) to evaluate workload from six dimensions:



Results



*IBM SPSS Statistics



*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 possible 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.*

