Nearmi: A Framework for Designing Point of Interest Techniques for VR Users with Limited Mobility

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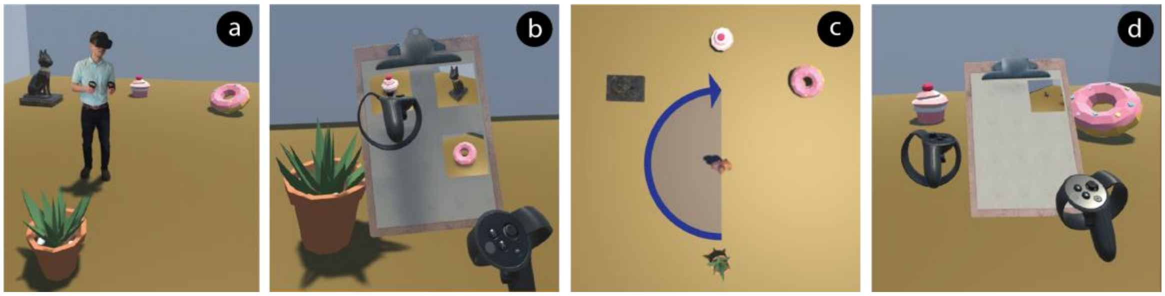

Figure 1. (a) A user in a virtual environment surrounded by points of interest (POIs). (b) The user pulls up a display of out-of-view POIs and selects a POI to orient to. (c) The user's first-person camera rotates to the selected POI. (d) The user faces the desired POI.

We propose Nearmi, a framework that enables designers to create customizable and accessible point-of-interest (POI) techniques in virtual reality (VR) for people with limited mobility. Designers can use Nearmi by creating and combining instances of its four components—representation, display, selection, and transition. These components enable users to gain awareness of POIs in virtual environments, and automatically re-orient the virtual camera toward a selected POI. We conducted a video elicitation study where 17 participants with limited mobility provided feedback on different Nearmi implementations. Although participants generally weighed the same design considerations when discussing their preferences, their choices reflected tradeoffs in accessibility, realism, spatial awareness, comfort, and familiarity with the interaction. Our findings highlight the need for accessible and customizable VR interaction techniques, as well as design considerations for building and evaluating these techniques.

CCS CONCEPTS • Human-centered computing ~ Human computer interaction (HCI) ~ Interaction techniques • Human-centered computing ~ Accessibility ~ Accessibility systems and tools

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* Place the footnote text for the author (if applicable) here.

Additional Keywords and Phrases: Virtual reality, Accessibility, Limited mobility, Design framework, Out-of-view, Point of interest

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1 INTRODUCTION

Many applications contain more virtual content than what can be displayed by a device at a given time, requiring users to scroll, pan, or zoom to find out-of-view information. For instance, users might be required to pan or zoom a virtual map to see the location of a restaurant, or to scroll a document to view a specific section. Over the years, researchers have developed numerous approaches to improve the experience of identifying and navigating to out-of-view points of interests (POIs) for various computing platforms, including virtual reality (VR) [23,32].

VR is an interactive technology that simulates the experience of being in a physical space. Users see the virtual environment (VE) through the viewport of their head-mounted display (HMD), which shows a limited region of the VE. VEs can contain objects, spaces, and avatars that are central to the VR app's objective. However, these POIs might be out-of-view at a given time. To address this problem, POI awareness techniques (which we refer to as "POI techniques") have been developed to help VR users become aware of out-of-view POIs using visualizations. These visualizations communicate spatial information, such as the direction of and distance to the POI, relative to the user's current position. The user is then expected to use head tracking, where the virtual camera is controlled by the HMD's position and orientation, to orient to the POI until it is within view [30].

Although head tracking is a convenient way for many people to explore VEs, it can be inaccessible to people with limited or restricted movement of their head or bodies. People with neck injuries or movement disorders such as cerebral palsy or muscular dystrophy might find it challenging or impossible to rotate their heads or bodies in a steady, fluid manner. In addition, situational impairments, which are functional limitations caused by the environment or an individual's physical state (e.g., sitting down) [41], can make head or body movement difficult.

Because POI techniques assume that users can easily control their virtual cameras to orient to out-of-view POIs, we need to imagine more accessible methods for POI interaction. But how should designers approach the process of creating accessible POI techniques for people with limited mobility?

We propose Nearmi, a framework that enables designers to create and customize accessible POI techniques for diverse user abilities and VR environments. The Nearmi framework has four components: (1) Representation: a visualization of off-screen POIs; (2) Display: a presentation of POI visualizations; (3) Selection: an interaction with the display to select a POI; and (4) Transition: a reorientation of the camera to the selected POI (Figure 1). Designers can use Nearmi to create various POI techniques by implementing different instances for each Nearmi component.

We explored the Nearmi design space by implementing instances of Nearmi that surface design considerations that that could be relevant to accessible POI techniques. We conducted a video elicitation study with 17 people who have limited mobility to understand how participants prioritized design considerations. Participants watched videos of different Nearmi implementations and were asked to select and discuss their preferences. We found that participants had similar rationale for liking or disliking individual implementations. However, each participant weighed trade-offs regarding accessibility, realism, spatial awareness, comfort, interaction familiarity, VE aesthetics, and expected immersion, highlighting the need for customizability.

Our contributions are threefold: (1) Nearmi, a framework for designing accessible POI techniques for VR environments; (2) a set relevant design considerations for implementing Nearmi (i.e., POI techniques designed by adhering to the Nearmi framework); and (3) empirical results from individuals with limited head or body movement regarding their perceptions of a set of Nearmi implementations.

2 RELATED WORK

The problem of how to visualize out-of-view information arises when screen-space is limited on displays. Researchers have addressed this problem on platforms such as mobile devices, wearables, augmented reality (AR), and VR. However, this problem has not been explored in VR for people with limited mobility. We present related work on the accessibility of VR, POI techniques in VR and other platforms, and accessible POI techniques designed for diverse use cases.

2.1 Accessibility in VR

Researchers have conducted several investigations to understand the accessibility barriers people with limited mobility might encounter when using VR systems. Gerling and Spiel [9] performed a critical analysis of VR technology and found that VR systems are not designed to accommodate minority bodies. Mott et al. [27] interviewed people with limited mobility about their VR experiences and constructed a list of seven accessibility barriers people might encounter when using VR. The Disability Visibility Project [43] surveyed wheelchair users and found that some people experience difficulties performing specific interactions in VR, such as crouching. Gerling et al. [8] discovered similar results in their survey of wheelchair users and applied those insights to build three prototypes of full-body VR games.

Our research complements these prior works by contributing a framework for designing accessible POI techniques for VR environments. As we continue to make VR technologies accessible to people of all abilities, it is important to have structured approaches to exploring solutions to complex design challenges.

2.2 POI Techniques

POI techniques are typically proxies overlaid on a display to signal the existence of out-of-view POIs [5]. Early techniques focused on visualizing off-screen POIs on mobile-based maps. For example, Halo [2] and Wedge [15] used shapes as proxies, where the location and size of a shape conveyed the direction of and distance to the corresponding POI.

Prior work also investigated the use of POI techniques in AR, VR, and full-coverage displays (e.g., systems that project a VE onto a physical space, such as CAVE [6]). This work suggested that the success of POI techniques was platform dependent [11,12,33].

The POI techniques discussed above convey distance and direction information, which helps in spatial orientation tasks. However, few POI techniques convey the identity of off-screen POIs, which can aid in exploring POIs. Prior work has suggested that users prefer knowing the identity of POIs when deciding how to orient the camera [13,23,38]. Lin et al used overlayed a real-time view of a POI onto the user's focal view (a.k.a., picture-in-picture) in order to display the identity of the POI. The rotation and position of the superimposed picture-in-picture also provided additional cues like the distance and the direction of the POI [23].

Although the POI techniques described above exist to help visualize out-of-view objects, these techniques do not help the user select and orient to a POI. Once a user is aware of an out-of-view POI, the next step is usually to orient to it so that it is within view. Mobile and PC-based selection and orientation techniques, such as Hopping [18] and EdgeSplit [17], allow users to select POI proxies to orient to. Unlike these techniques, existing AR and VR techniques lack control or affordances and instead rely on head movements [11,14,23,36] or button presses [32] to orient the user.

2.3 Accessible POI Techniques

Within the accessibility community, POI based techniques have focused on identifying sounds of interest for deaf and hard of hearing (DHH) individuals [16,22,24]. Research suggests that DHH users want to know the source and location of peripheral sounds in their environments [20,25]. For instance, AR users want to know the sound source and type (e.g., speech vs. non-speech sounds) while having a flexible system that accommodates their preferences for directional granularity and screen layout [19].

2.4 Summary

Prior work has shown that visualizing and orienting to out-of-view POIs are important for VR users. From an accessibility perspective, it is also important to provide users with affordances and controls over the experience [27]. No prior work, however, has addressed all three of these issues in a single interaction technique. To bridge this gap, we developed a framework that enables the creation of accessible POI techniques that not only identify out-of-view objects in VR, but also enables users with limited mobility to select and orient to them.

3 NEARMI

We present Nearmi, a framework for designing accessible POI techniques in VR. POI techniques designed with this framework would enable users to see representations of out-of-view POIs on a display, select the POI they want to view, and ultimately transition towards the POI's direction. The Nearmi framework outlines a design space that can be explored by implementing instances of Nearmi's four components, each of which we discuss below:

- Representation
- Display
- Selection
- Transition

Representation:

POIs are represented as cues to signal their existence in a VE. *Representations* can be visual, auditory, or haptic. Without a *representation*, users would be unaware of nearby POIs. Some *representations* also convey information about properties of POIs, such as their distance and direction [2,15] relative to the user's position.

Representations in existing POI techniques include circles (halos) [2], triangles (wedges) [15], arrows [12], and picture-in-picture views [23]. The *representations* designers choose for POIs can depend on numerous factors, including the style of the VE and the tasks available in the environment.

Display:
Representations of POIs are presented on a *display*. Displays act as a canvas for the arrangement and presentation of POIs. In prior work, *representations* were displayed by being directly superimposed over the environment [11] or on an object in the environment [23]. *Displays*, like *representations*, can also encode information about distance and direction of a POI [23]. Many POI techniques only implement *representation* and *display* components and assume that the user can orient the environment or themselves towards POIs independently. Nearmi includes *selection* and *transition* components to automatically reorient users towards POIs of their choosing.

Selection:
POI techniques that require little movement (of head or body) must allow users to indicate to the system which POI they would like to orient towards, which is achieved through the *selection* component. A user can select a POI in many ways, through gesture, sound, eye movements, or input devices, to name a few.

Transition: A *transition* is needed to orient the user toward a POI after it has been selected, either by repositioning the user or the environment. *Transition* serves as an automatic reorientation that removes the burden on users to rotate their heads or bodies. Some prior work has explored *selection* and *transition* in POI techniques. For example, in work by Pavel et al. [32], users pushed a controller button and the system automatically oriented their view to the subject of the 3D video. This technique worked without *representation* and *display* components because it was designed to be used with 3D videos, which usually only have one or two foci in a scene.

Users engage with POI techniques on two fundamental levels: presentation and interaction. All POI techniques must implement both *representation* and *display* components—the presentation. Most prior techniques presume users can control the interaction by orienting the environment or themselves toward POIs independently. As a result, the degree to which people with limited mobility can interact with POI techniques will be determined by the general accessibility of VR systems. Although it will take time to envision and build accessible VR systems, frameworks like Nearmi can help accelerate the design of accessible techniques for VR applications.

3.1 Benefits of Nearmi as a Design Framework

We identified four benefits of the Nearmi framework for VR users and designers: (1) it foregrounds accessibility for POI techniques, (2) it structures the design process, (3) facilitates evaluation, and (4) affords customizability of POI techniques. We discuss each benefit below.

3.1.1 Foregrounds Accessibility

POI techniques in previous works typically only included representation and display components, as these techniques presume users can orient themselves towards POIs. However, the process of orienting to a POI can be challenging or impossible for VR users with limited mobility who cannot easily move their heads or bodies. Nearmi's transition component ensures POI techniques designed using the framework will be accessible to VR users who cannot easily move themselves to view a POIs. However, implementation of all Nearmi components does not necessarily guarantee the POI technique will be accessible. Designers must consider how specific component implementations can affect accessibility as well.

3.1.2 Structures the Design Process

The Nearmi framework provides designers with a blueprint for building accessible POI techniques. Designers can then explore the design space by mixing and matching implementations of Nearmi components while retaining the basic functionality of a POI technique.

3.1.3 Facilitates Evaluation

When evaluating POI techniques, Nearmi can help designers identify the components that might lead to accessibility or usability breakdowns. Once the component (or combination of components) that is causing the issue is identified, designers can swap in an alternative implementation of the component without entirely redesigning the POI technique or altering its core functionality. Nearmi also enables direct comparison of different implementations in an evaluation.

3.1.4 Affords Customizability

Nearmi could be directly integrated as a setting in VR applications. This setting could enable users to try different implementations of Nearmi and choose a combination that best suits their abilities and personal preferences. Customizability is known to enhance the accessibility of interaction techniques [1,29].

3.2 Design Considerations for Nearmi Implementations

As mentioned above, the Nearmi framework alone cannot guarantee that a POI technique is accessible. VR techniques are often built and evaluated based on various design considerations that affect the overall experience of being in VR. We were interested in exploring the relationships between different design considerations and their manifestation as trade-offs.

We explored the design space based on seven design considerations including accessibility, usability, realism, spatial awareness, user comfort, user familiarity with an interaction pattern, and task objective. We identified these design considerations from papers on VR interaction techniques [3,21], and accessible technology for people with motor impairments [43].

3.2.1 Accessibility

Accessibility could potentially impact three components of Nearmi. For example, a representation must be clearly visible, audible, etc. Some displays and selection implementations might not be accessible for people with limited reach, control or stability.

3.2.2 Usability

Usability was a design consideration for every component of Nearmi. Usable designs enable users to form mental models of technology without much cognitive load.

3.2.3 Realism

Realism could affect all four components. The representation could be a duplicate of the POI (more realistic) or a symbol (less realistic). A display can be the environment itself (more realism), an object in the environment (more realism), or a UI (less realism). Selection can range from touch (more realistic) to ray-cast selection (less realistic). And the transition to orient the user POI can could be smooth, as if a user were turning, or instant as if they immediately reoriented to the POI (less realistic).

3.2.4 Spatial Awareness

It can be important for the user to understand where they are relative to other objects in the VE depending on the task. Transition might affect a user's spatial awareness depending how much of the environment is presented and the duration of the transition. Representations can be arranged on a display to convey spatial information (e.g., direction), and POI representations can include contextual information that might provide awareness of other items or locations.

3.2.5 User Comfort

User comfort is important for most VR techniques. Simulation sickness is well documented when the user moves in the virtual world without a corresponding movement happening in the physical world. Transition implementations that automatically rotate the virtual camera would be more suspectable to inducing simulation sickness, but designers can utilize approaches that reduce simulation sickness during VR camera movements [37]. Selection also impacts user comfort, and the selection method should not be cumbersome to use.

3.2.6 User Familiarity with Interaction

Many users might be unfamiliar with VR interactions, regardless of their functional abilities, because VR is still emerging as a consumer technology. Therefore, designers can leverage common interaction patterns from other devices, (e.g., joystick panning on a gaming console), to scaffold the process of learning how to interact in VR. Selection would be affected by this design consideration depending on whether the designer imports interaction techniques from other devices.

3.2.7 Task Objective

There can be VR experiences where efficiency matters more than realism. Designing for efficiency, however, might take away from the richness of the experience or challenge of the task. Therefore, it is important to consider the context in which POIs are used and whether the technique could interfere with the purpose or objective of the experience.

Most of these design considerations are relevant for VR techniques in general. However, we were interested in how basic design considerations relate to the accessibility of a POI technique. For example, does increased accessibility mean decreased realism? How do some design considerations impact others in implementations of Nearmi? In the next section we discuss how the design considerations above guided the design process.

4 IMPLEMENTATION

We used the Nearmi framework to implement an initial set of component instances that exemplified the design considerations above. Although we could have designed any number of Nearmi component instances, we focused on this subset to surface tradeoffs in our design considerations. In this section, we describe the implementation of eleven Nearmi components and how components work together to help users identify and orient to out-of-view POIs.

4.1 Representation

We implemented two representations: a *mesh* and a real-time view of the POI that we call *portal-views* (Figure 2). *Meshes* are static, textureless, colorless, miniaturized versions of the POI mesh that do not provide details about the POI or its surrounding environment. *Portal-views* are live previews that show the POI and some of its surroundings.

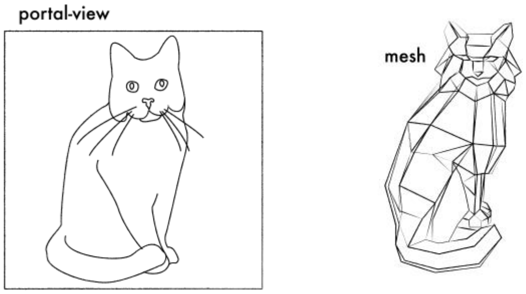

Figure 2. The two Representations implemented with Nearmi. Portal-view icon of the POI in real-time (left). 3D miniature mesh icon of the POI mesh (right).

Mesh and *portal-view* representations exemplify the tradeoffs between accessibility and spatial awareness. The *mesh* representation could make it easier to identify the POI because it stands out against the background. However, the *mesh* representation lacks detail and information about objects around it. Lack of context might make it more difficult to understand where the POI is in relation to other parts of the VE. On the other hand, *portal-view* might not stand out against the background, making it difficult to see, but could provide important contextual information to support users' spatial awareness.

4.2 Display

We implemented two displays: *attached-to-object* and *floating* (Figure 3). *Attached-to-object* displays, as the name suggests, can be attached to virtual objects or parts of a user's avatar. Representations float in the scene on a *floating* display. Our implementation of the *floating* display tracks the user's camera to ensure that icons on the display are always visible.

These displays embody a trade-off in accessibility and realism. The *attached-to-object* display simulates interacting with a display in the physical world, which could enhance realism. However, the *attached-to-object* display might be inaccessible if users cannot see the display in the scene, for example because they cannot hold their arm in view if the display is attached to their hand. Therefore, we implemented the *floating* display so that it was always visible. Constant visibility, however, might reduce realism because it does not have an equivalent in the physical world.

4.3 Selection

We implemented four selection instances: (1) *tap*, (2) *ray-cast*, (3) *console*, and (4) *wand* (Figures 3 and 4). *Tap* borrows from the touchscreen interaction paradigm by requiring users to "touch" or intersect their controller and a representation to select it.

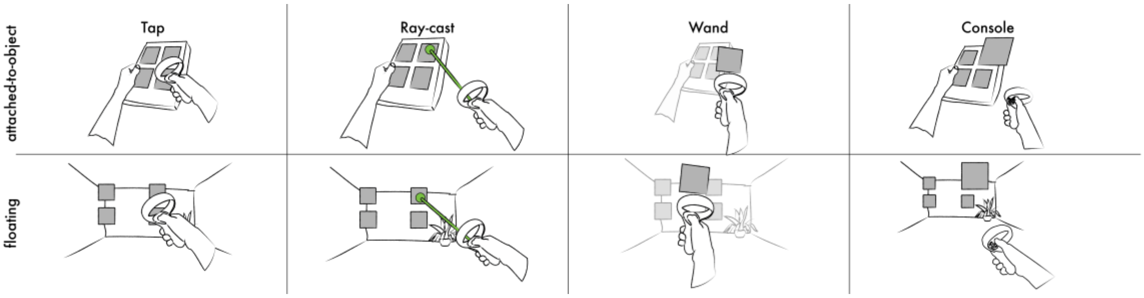

Figure 3. Nearmi's display and selection combinations. Columns from left to right show selection instances: tap, ray-cast, wand, console. Rows from top to bottom show display instances: attached-to-object, floating.

To operate *ray-cast*, the user points the ray emitting from one of their controllers and intersects it with a representation. A button-press on the controller, typically the trigger, initiates the selection. *Console* selection enables users to press the controller's joystick left or right to scroll through the representations. As the user scrolls through the icons, they grow larger when in focus. Users can either scroll to the next representation or select the in-focus representation. The user selects a representation by pressing the trigger button. The *wand* selection (Figure 4) requires users to tap a representation. The representation is then transferred to the controller that performed the tap. Users move the representation toward their headsets and the selection is made when the representation and headset intersect.

4.3.1 Design Considerations for Selection

We implemented these selection techniques to illustrate the relationships between multiple design considerations including accessibility, usability, realism and familiarity with interaction. *Tap* enhances realism because it has a physical analogue. In addition, users will likely already be familiar with this interaction paradigm because of the ubiquity of touchscreens. However, using *tap* might be difficult for users who have difficulty reaching or stabilizing their arms. VR users will likely be familiar with *ray-cast* because it is a common pointing technique used in many VR applications [4]. Another benefit of *ray-cast* is that it enables users to select objects without reaching. However, *ray-cast* might be inaccessible to people with difficulty pointing. With *console* selection, users can quickly and accurately select a representation, demonstrating usability. Also, because the thumb (or any finger) is the only body part needed to invoke selection, *console* can be accessible for users with limited mobility. However, *console* lacks affordances, requiring users to recall how to perform the interaction. Lack of affordances is often categorized as a usability issue [28].

Wand enables users to bring representations near their faces to examine them up close, enhancing visual accessibility. This technique is especially useful for examining mesh icons: individuals can examine meshes from multiple angles. However, *wand* requires users to reach and move their arms, which can make it inaccessible.

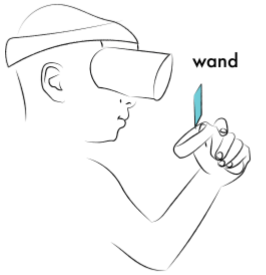

Figure 4. Wand: After tapping an icon as shown in Figure 3, the user brings an icon towards his/her headset. A selection is made when the headset and icon collide.

4.4 Transition

There are many ways to orient the first-person camera, each of which has tradeoffs. We implemented three transitions: (1) *continuous*, (2) *discrete*, and (3) *instant* (Figure 5). The *continuous* camera transition smoothly rotates the scene around the user simulating what the user would see if they were to turn their head toward the POI. We chose a rotation speed of 30 degrees per second because there is evidence to support that this is a comfortable speed [37]; Still, the speed can be adjusted in our implementation. The *discrete* camera transition rotates the camera using configurable angle increments towards the POI. We used 30 degree increments because prior work has shown that it is a comfortable angle to rotate the camera [37]. The *instant* transition immediately orients the camera toward the selected POI. The transition is visualized as a camera cut.

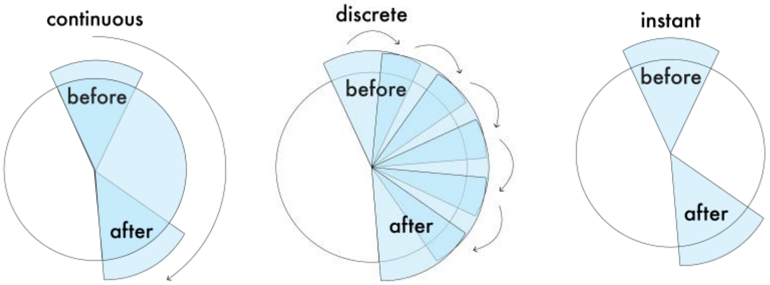

Figure 5. The three camera transitions implemented in Nearmi. The first-person camera rotates smoothly in the continuous transition (left), jumps by 30-degree increments in the discrete transition (middle), and instantly cuts from a starting orientation to face the POI in the instant transition (right).

We implemented *continuous*, *discrete*, and *instant* transitions to surface trade-offs in spatial awareness, user comfort, and realism. *Continuous* camera rotations can induce simulator sickness [35], but provide information about the environment during the transition, which can enhance spatial awareness. *Discrete* transitions can induce less simulation sickness than *continuous* transitions [37], however they could also be perceived as less realistic because there is no physical analogue. The *instant* transition is the least realistic of the transitions we implemented, however, it is unlikely to induce simulation sickness [34]. Another trade-off with the *instant* transition is that users might not be able to maintain spatial awareness because they do not see the environment during the orientation process, which is possible with *continuous* and *discrete* transitions.

4.5 Summary

Nearmi is a framework with four components—representation, display, selection, and transition—that supports the design of accessible POI techniques for people with limited mobility. We implemented 11 initial instances of these components that reflect trade-offs in accessibility, usability, realism, spatial awareness, user comfort, interaction familiarity, and task objective. We were interested in exploring the Nearmi design space to understand how different implementations of Nearmi could speak to the design considerations we identified in prior work. With just these 11 instances, users can already create 48 unique Nearmi implementations (2 representation × 2 display × 4 selection × 3 transition) illustrating the design consideration of customizability and extensibility. It would be impossible to build all possible implementations of Nearmi, but we chose to implement this initial set to demonstrate part of the design space and to surface trade-offs in the design considerations we identified.

4.6 High-level Implementation Overview

To address the customizability and extensibility design consideration, we implemented Nearmi components as a set of Unity scripts written in C#. The basic building block of a Nearmi technique is the display mechanism, that is, an interface that shows POI icons. It is implemented in the `POIDisplay` base class. To render icon content, each display contains a representation mechanism implemented in the `POIIconManager` base class (Figure 6).

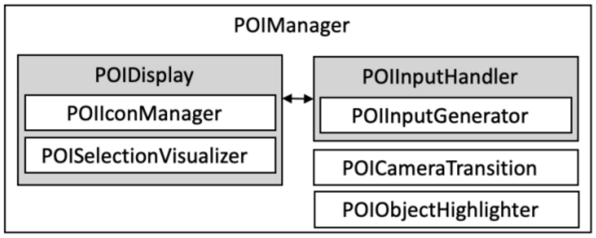

Figure 6. A high-level overview of the Nearmi framework manager, the mechanism base classes, and their relationships.

To support interaction with the display content, each display is coupled with a selection mechanism, which is implemented in the `POIInputHandler` and `POIInputGenerator` base classes. The generator provides raw inputs and the handler pre-processes them before publishing them to other mechanisms. The information exchanged between the display and the input handler is limited to what is required for providing interaction feedback to the user. For example, the display contains a supporting mechanism for icon selection visualization, which is implemented in the `POISelectionVisualizer` base class.

The `POIManager` manages the display itself, including showing or hiding it and providing it with POIs. The manager is also responsible for discovering POIs in the environment and triggering environment updates once the user selects a POI. In particular, it uses events from the selection mechanism to trigger a transition mechanism, which is implemented by the `POICameraTransition` base class. The manager can also illuminate the selected POI using the object highlighter implemented in the `POIObjectHighlighter` base class.

The developer is responsible for the following steps to connect an app to Nearmi: (1) calling functions in the `POIManager` to toggle display visibility, (2) marking POIs in the scene by attaching the `PointOfInterest` script provided by the framework, which enables Nearmi to discover the POIs, and (3) mapping system inputs to the input generator.

5 USER INTERVIEWS

The goal of our study was to identify design considerations and trade-offs that were important to people with limited mobility when choosing their preferred implementation of Nearmi. We wanted to understand how they thought about trade-offs and why they were willing to make specific trade-offs. We conducted a video elicitation study [10] with seventeen individuals with limited mobility. Video elicitation, which is an interview technique derived from photo elicitation, is used to uncover layers of meaning through images, videos, and other visual media. Images elicit emotions, memories, and information in a more detailed and grounded way than conventional interviews [10]. Interviews are appropriate for investigating how people perceive phenomena and why they perceive it the way they do [40]. While participants' perceptions are reflective of how they evaluate VR based on video alone, previous research has demonstrated that people with functional impairments often watch other people use the technology, through online videos or friends, to decide whether it is worth investing in (section 6.1.2, [43]). Therefore, the results of our study indicate how they might evaluate POI techniques at the pre-adoption stage.

Identifier	Gender	Age	Condition	Preferred Nearmi implementation
P1	M	26	Spinal muscular atrophy	Portal+attached+console+continuous*
P2	M	26	Muscular dystrophy	Portal+attached+console+instant
P3	M	26	Arthrogryposis	Mesh+floating+console+discrete
P4	M	20	Muscular dystrophy	Mesh+attached+console+continuous
P5	W	32	Muscular dystrophy	Mesh+floating+console+continuous
P6	M	24	Cerebral palsy	Portal+attached+ray+continuous
P7	W	36	Muscular dystrophy	Mesh+attached+console+discrete
P8	M	37	Quadriplegia	Mesh+attached+tap+continuous
P9	M	29	Hemiparesis	Portal+attached+console+continuous*
P10	M	24	Muscular dystrophy	Mesh+attached+tap+instant
P11	W	30	Cerebral palsy	Portal+floating+ray+continuous
P12	M	26	Cerebral Palsy	Portal+attached+ray+continuous

P13	M	61	Difficulty moving arms	Portal+floating+tap+continuous
P14	M	26	Cerebral palsy	Mesh+floating+ray+continuous
P15	W	33	Underdeveloped left hand	Portal+attached+console+continuous*
P16	M	33	Cerebral palsy	Portal+attached+tap+continuous
P17	M	34	Spinal cord injury	Portal+attached+console+continuous*

Table 1. Participant demographics and preferred Nearmi implementations. * signifies the single non-unique preference.

5.1 Participants

We recruited seventeen participants through email invitation (average age of 31, *SD*=9). Four identified as women and 13 identified as men. We compensated participants with a $50 Amazon gift card. Twelve participants had prior VR experience. Their VR usage ranged from every few days to a few times a year. Overall, they rated themselves an average of 2.1 (*SD*=1.1) in terms of VR expertise with 1 being novice and 5 being expert. By contrast, all participants rated themselves an average of 4.5 (*SD*=.7) in terms of computer expertise on the same scale. Participants reported a range of conditions that impacted their abilities to interact with computers (Table 1). Their most common challenges were poor coordination (n=12), low strength (n=11), and difficulty in gripping (n=10). They also reported motor difficulties that affected their neck mobility, such as stiffness (n=11), low strength (n=7), and pain (n=6).

5.2 Apparatus

We recorded videos of 48 Nearmi implementations ({portal-view, mesh}×{attached-to-object, floating}×{tap, ray-cast, wand, console}×{continuous, discrete, instant}). Videos averaged 25.7 seconds (*SD*=4.3).

Videos captured a user visualizing and orienting to POIs in an alchemist's lab using different Nearmi implementations [45] (Figure 7). The user oriented towards the POIs in the same order in each video. We added Nearmi implementations to the game using the steps outlined in the implementation section. In our implementation of the attached-to-object display, we presented icons on a magic amulet because it reflects the game's occult theme. Videos were presented via screenshare on Zoom[1], a video conferencing application.

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[1] https://zoom.us/

Figure 7. The alchemy lab VE used to demo Nearmi. Environment by Unity Technologies (https://github.com/Unity-Technologies/VRAlchemyLab).

5.3 Procedure

Participants completed informed consent and demographic questionnaires prior to the study. At the start of a session, the researcher and participant joined a Zoom meeting room with both parties' video and audio enabled. With participants' consent, the researcher turned on Zoom's record feature.

After describing the study, the researcher asked questions regarding participants' use of VR and whether limited head or body mobility impacted their use. The researcher then described the purpose of Nearmi, its components, and how to interact with the implementations. With the webcam, the researcher demonstrated physical interactions for selection methods with Oculus Rift VR controllers. While describing Nearmi, the researcher supported the explanation with visuals (Figures 1-5) on a slide deck. The researcher then walked through an example video of a person using Nearmi and explained what was happening as the video was playing.

The remainder of the study consisted of four similar phases. In each phase the participant watched videos depicting different Nearmi implementations. After watching the videos, the researcher asked the participant about their preferred component instances, as well as questions related to the learnability, perceived ease-of-use, and perceived usefulness of their preferred combination. If the participant thought the combination was useful, we asked in which scenarios they would want to use it. It is important to understand perceived ease-of-use and usefulness, as they can indicate future adoption [7,39].

In the first phase, the videos depicted the different combinations of representations and transitions (2 representation × 3 transition implementations) while the display and selection components stayed the same (attached-to-object display with console selection). In the second phase, the researcher showed the participant eight videos in which the display and selection components (2 display × 4 selection implementations) changed while the representation and transition instances remained the same. The representation and transition implementations were those the participant preferred in the first phase. Then the researcher showed the participant a video of the participant's preferred Nearmi implementation built using component instances they identified in the first two phases. The researcher asked if the Nearmi implementation was still the participant's preferred combination and how it could be improved. We summarize the three phases in Table 2.

	Representation	Display	Selection	Transition	Videos	Outcome
Phase 1	All	Attached-to-object	Console	All	6	Participant's preferred Representation × Transition

Phase 2	Preferred Representation	All	All	Preferred Transition	8	Participant’s preferred Display × Selection
Phase 3	Preferred Representation	Preferred Display	Preferred Selection	Preferred Transition	1	Confirmation of Preferences

Table 2. A summary of the videos participants watched and the outcome of each phase.

5.3.1 Analysis

We transcribed the recorded calls and performed a thematic analysis of the transcripts [31]. We used the design considerations as deductive themes. We also inductively identified patterns and categories in the transcripts that summarize participants’ thoughts on Nearmi’s implementations.

6 RESULTS

Our findings can be categorized into three groups. First, we demonstrate the need for accessible POI techniques in VR. Next, we provide user feedback on individual Nearmi component implementations and their combinations. We highlight design considerations that participants discussed for each component. Finally, we present how participants’ envisioned using Nearmi in VR. When we use the word “immersion”, it is because the participant volunteered the term. We could not evaluate immersion because of the nature of our study procedure.

6.1 Impact of Mobility Limitations on VR Use

We begin with challenges that participants experienced turning their heads or bodies in VR and how these challenges impacted their ability to use VR.

6.1.1 Challenges Related to Head or Body Rotation

Fifteen of 17 participants reported difficulties turning their heads or bodies. Of the 12 participants who had used VR at least once, ten found it difficult to move their bodies or heads while using VR. Six of the 17 participants reported that they did not have difficulty moving their heads but found it challenging to look behind themselves because it required them to turn their wheelchairs. For P1, this challenge was exacerbated by the fact that the headset obscured his vision of the physical world. P1 said,

> “When I'm sitting in a wheelchair and I'm wearing a headset, I have to be careful that I don't hit any furniture or injure my legs or something. So, I would kind of take the headset, push it up a little, and try to see underneath it before I turn” (P1).

P4 and P6 reported that their wheelchair headrests made it difficult to turn their heads because the VR headset would bump up against the headrest. As P4 said,

> “I have a headrest on my wheelchair and so that kind of gets in the way. And then moving my head around with that (headset) and getting like stuck with the headrest on my chair” (P4).

Four participants felt that the VR headset was heavy, which limited their ability to turn their heads. Seven participants had limited neck mobility, neck spasms, neck pain or stiffness that made it challenging to use the head tracking feature. P16 describes this issue and its effect on his experience of immersion:

> “I don't necessarily like have a limited range of motion, but I just have like a lot of stiff neck issues. Like I remember when you try to move this way *(turning head to side)*, it, it just didn't—it like didn't feel natural so that takes you out of the immersion.” (P11)

VR often requires two hands to view, interact with, and navigate virtual worlds. P15 expressed that the challenge for her was not so much moving her head but rather controlling the virtual camera and performing all other interactions with one hand. She explained,

> “I mean the biggest issue for me with (controlling) camera angles is not being able to turn my head or stand for the most part, it’s that usually what's required with (controlling) camera angles is most games have two joysticks and so to be able to do that with one hand, I just can't [...] So in this scenario what if I did need to look at the pig's head and then do something with the staff at the same time?” (P15)

6.1.2 Impact of Limited Head and Body Rotation on VR Use

Challenges related to head and body rotation in VR impacted participants’ VR use. In the best case, participants were able to employ workarounds. For instance, they used joystick panning (P3) and slight head turns (P6) or played games where the majority of content appeared in front of them. Since these workarounds are not always possible or desirable, participants sometimes researched games before buying them to “*make sure someone's (the user’s) head isn't like jumping around everywhere*” (P3). None of the participants owned a VR system but had used VR through social ties, at arcades, conferences, and in research studies.

Unfortunately, the challenges related to head turning led two participants (P5 and P13) to abandon their VR systems. P5 explained that she was excited to try VR and bought a PlayStation VR system when it was first released. However, many of the games she wanted to play required body or head movement. She eventually abandoned her VR system, saying,

> “There wasn’t like a difficulty setting so I couldn’t, like, just say, oh instead I’m gonna do it on a lower difficulty, or you know, just be worse at it, you know. So, if I could have done that, I probably would have changed it and maybe kept playing” (P5).

Participants have found some ways to overcome limited head and body mobility in VR, yet as our data and other work [26,27] reveal there is still a need for more accessible solutions for this user group.

6.2 Design Considerations of Nearmi Implementations

We now present the next level of findings, which are participants’ perceptions of Nearmi and its implementations.

6.2.1 Representation

The ideal choice of POI representation type appeared to be driven primarily by a tradeoff between the level visual information (*3.2.4 spatial awareness*) and challenge of discovering the object (*3.2.7 task objective*). Nevertheless, participants were almost evenly split between portal-view and mesh for their representation preference.

Ten participants liked the portal-view representation. Their reasons were that they knew exactly what they were looking for in the scene (*3.2.7 task objective*), they could see what was around the object (*3.2.4 spatial awareness*), and portal-view aligned better with the game aesthetic (*new design consideration: VE aesthetic*). By contrast, three participants disliked the portal-view because by clearly showing POIs, it took away the challenge of discovery (*3.2.7 task objective*), which they enjoyed. P5 expressed: *"Sometimes I don't want all the answers given to me. So, there was an element of like a, kind of a hide-and-seek thing to that (mesh) as well." (P5).*

Seven participants preferred the mesh representation. Their reasons were that it maintained the challenge of discovery to find the object in the scene (*3.2.7 task objective*) and it looked like a miniature object rather than an image, underscoring the 3D nature of VR (*3.2.3 realism*). Reasons for disliking mesh were the same reasons that some participants liked the mesh: it had an additional layer of abstraction, making it difficult to recognize the object in the scene (*3.2.7 task objective*).

6.2.2 Display

Visual accessibility and reachability (*3.2.1 accessibility*) of the display were key factors for participants' preferences, along with realism (*3.2.3*).

Eleven participants preferred the attached-to-object display because it was easier to see the representations (3*.2.1 accessibility*), it felt more "natural" (*3.2.3 realism*), easier to reach (*3.2.1 accessibility*), and it integrated with the aesthetic of the environment (*VE aesthetic*). P3 disliked the attached-to-object display because the icons were close together, and he predicted it would be difficult to accurately make a selection (unless the console selection was being used) (*3.2.1 accessibility*).

On the other hand, six participants preferred the floating display because they thought it would be more "immersive" (*new design consideration: uniqueness to VR*), and there was more space between representations (3.2.1 *accessibility*). The main reason for disliking the floating display was that it made it difficult to distinguish the icons from the background (*3.2.1 accessibility*).

6.2.3 Selection

Participants' choices for selection types were motivated by trade-offs in accessibility (3.2.1) and realism (3.2.3). Overall, they preferred selection techniques that required the least arm movement (console or ray-cast) (*3.2.1 accessibility*), yet some participants appreciated mechanisms that increased realism (tap or wand) (*3.2.3 realism*).

Eight participants preferred the console selection technique. Their reasons were that it required the least amount of arm movement (*3.2.1 accessibility*), users could rest their arms while making a selection (*3.2.1 accessibility*), it was one-handed (*3.2.1 accessibility*), and the interaction was familiar because it was similar to using game controllers (*3.2.6 user familiarity with interaction*). Five people disliked the console selection technique. For these participants, being able to move and interact with their virtual hands was a major reason for using VR over other gaming systems (*uniqueness to VR*). To reinforce this point, P15 said:

> “if you have the controller and it can sense motion, why wouldn't you want to use it? If I'm doing VR, I want what makes VR special, I can use a joystick on any other gaming system” (P15).

P8 and P13 evaluated selection techniques based on the visual animation of the virtual controllers making a selection, assuming the physical selection could be made using gaze input, which was their primary input method. The reason they disliked the console was because the virtual hands did not interact with anything, taking away from the VR experience.

Four participants preferred ray-cast. Reasons were that it required less arm movement and reaching (*3.2.1 accessibility*). They also liked that this interaction technique is commonly used in VR for performing other actions (e.g., selecting objects, locomotion) (*3.2.6 user familiarity with interaction*). On the other hand, some participants disliked ray-cast because it still required some arm movement and coordination (*3.2.1 accessibility*). Two other participants reported difficulty with aiming in VR. Finally, P8 disliked ray-cast because he felt that it did not fit with the theme of the VE and was better suited to a sci-fi environment (*VE aesthetic*).

Four participants preferred tap. P8 and P13 enjoyed watching the virtual hands interact with objects. P8 said:

> “Even though I can't like physically make that tap motion, I would enjoy having that animation. I just like the aesthetic of the tap because it looks like you're reaching out to the menu to select the thing” (P8).

In other words, they wanted to watch their virtual bodies move in ways that their physical bodies could not (*uniqueness to VR*). Also, P1 liked that the tap interaction was similar to touchscreen interaction (*3.2.6 user familiarity with interaction*). However, many participants disliked tap because it required reaching out, which was difficult to do (*3.2.1 accessibility*).

Only one participant, P16, preferred wand. The majority of participants disliked wand because it required the most arm movement (*3.2.1 accessibility*). However, P8 also liked wand because using gaze input, he did not have to factor in arm movement and it leveraged the essence of VR that makes it different from other technology (*uniqueness to VR*). He said,

> “It kind of seems like another cool opportunity to just like hammer in the fact that you're playing VR and it's awesome. Just having another object move towards you” (P8).

6.2.4 Transition

Our participants traded off spatial awareness (*3.2.4*), realism (*3.2.3*), and comfort (*3.2.5*) when selecting their preferred camera transition technique.

Twelve participants preferred continuous transition because it gave them a better awareness of their environment (*3.2.4. spatial awareness*) and felt more “immersive” and “natural” compared to the other transitions (*3.2.3 realism*).

Two participants preferred the discrete transition because it was familiar (*3.2.6 user familiarity with interaction*) and seemed faster (*3.2.2 usability*) than the continuous transition. Most participants disliked it because they felt it was “jerky”, “robotic”, and “unnatural” and reminded them of video lag (*3.2.3 realism*).

A couple of participants preferred the instant transition because it was the most direct transition and was faster than the other transitions (*3.2.2 usability*). On the other hand, some participants disliked the instant transition because they felt that they were missing out on important spatial information (*3.2.4 spatial awareness*) and it was less "immersive" than the other transitions (*uniqueness to VR*).

6.2.5 Display × Selection Combination

A few participants, pointed out that an interaction between the display and selection affected the overall accessibility of the Nearmi implementation. In particular, the floating display with the tap or wand interaction would have been inaccessible to people who find it challenging to perform reaching movements (*3.2.1 accessibility*). P3 explained that he would have chosen the attached display because it was more accessible than the floating display if he was limited to using tap or wand selection. He said,

> "The floating versus attached thing became simply a matter of like personal visual preference and contrast, whereas if I was considering like a tap and wand then I would have had a total different reason for preferring attached which is I simply couldn't reach them (the floating icons)" (P3).

On the other hand, P17 pointed out that the attached-to-object display had less space between icons, making it difficult to accurately select an icon (*3.2.1 accessibility*). In addition, P8 expressed that he would use the floating display and ray-cast selection combination because it would work well with gaze input (*new consideration: input device*). Therefore, the combination of display and selection implementations can have unique accessibility implications that are not apparent based on their individual components.

6.2.6 Accessibility Via Customizability

While participants considered similar tradeoffs in accessibility (*3.2.1*), expected immersion (*uniqueness to VR*), and other factors, they nevertheless created 13 unique preferred Nearmi variants, highlighting the need for customizability. In fact, five participants explicitly mentioned this customizability is important for accessible design. For instance, P5 said,

> "When you have a physical disability, it's like, you just have to have options. Having this kind of flexibility would definitely help in all kinds of situations in VR" (P5).

P2 also illustrated the need for alternative input methods when a user cannot move in VR traditionally (*input device*):

> "It (Nearmi) makes it a lot more accessible for people that can't even move around traditionally. So, it's not going to be like you're stuck to have to move your arms and things. You're able to just use a joystick" (P2).

Moreover, P4 highlighted the need for options because different people have different types of mobility:

> "I know people who have strong arm movement, but not so much with dexterity. They might do just fine with a tap. Even though we both have limited mobility, people have different types of mobility" (P4).

P11 and P16 had a combination of perceptual and motor impairments reinforcing the need to design for diverse abilities. They assessed Nearmi components based on whether it would provide a frame of reference to support their spatial understanding.

6.3 Applicability of Nearmi to Real Scenarios

To investigate participants' potential adoption of Nearmi implementations, we asked for feedback regarding their expected learnability, perceived ease-of-use and usefulness [7,39]. All participants believed Nearmi would be easy to learn. All but three participants expressed it would be easy to use because the interaction felt "natural" and "intuitive" (*3.2.3 realism*), and they were already familiar with console interaction (*3.2.6 user familiarity with interaction*). The remaining participants expressed that they thought the Nearmi implementations would be easy to use as long as their preferred input method was compatible (*input device*), the VR controllers were easy to use (*3.2.1 accessibility, 3.2.2 usability*), and if it integrated well with other interaction techniques for locomotion and object manipulation.

All participants said they would use Nearmi implementations in VR except P15, who said it would depend on the task (*3.2.7 task objective*). P4 said, *"This like solution is definitely an improvement on how I understand current methods of looking around*" (P4). Participants envisioned using Nearmi implementations in a variety of scenarios, including environment exploration, social VR, games, and 360 videos. P9 thought Nearmi would work well in an escape room:

> "(Nearmi would be useful) like where you need to solve puzzles or whatever, that would be something where this would be—being able to continuously move the camera and being able to see the whole room rather than just teleporting from one angle to the next, that (Nearmi) would be very helpful. I mean, personally, if there was a game that came out, if there was like an escape room with this (Nearmi), like, I would probably go buy a VR right now, so." (P9)

P1 explained that Nearmi would be especially useful during game startup:

> "Nearmi would be useful in like your home kind of setting, and you just want to equip stuff before you head out into the world. And this (Nearmi) would just make it kind of convenient, because it's a known location. There's no point in game mechanics and trying to make you look around to find stuff" (P1).

While some participants felt Nearmi would be most suitable for slower paced, exploratory VR experiences, A handful of participants could see Nearmi in faster-paced, first-person shooting games where it could be used to auto-target:

> "It (Nearmi) would be super helpful in a shooting game. I can see it being integrated into that really nicely where it kinda just like auto-targets for you if that's the difficulty level you want it to be at" (P5).

6.4 Summary

Our findings highlight the need for accessible viewing techniques for exploring VR environments for people with limited mobility. As a first step, we gained insight into participants' decision-making process when evaluating

Nearmi and its component implementations. Although participants had similar justifications for liking or disliking implementations, they created 13 unique Nearmi variants (Table 1), highlighting the need for customizability.

7 DISCUSSION

We discuss design considerations that were important for participants when they identified their preferred Nearmi implementation, the need for customizability, and the tension between standardization and customization in the design of VR techniques. We also discuss the need to establish criteria for evaluating accessible VR techniques.

7.1 Design Considerations Identified by Participants

Participants discussed most of the design considerations in the form of trade-offs. One of the main trade-offs they considered was between accessibility and realism. With a few of the Nearmi implementations, particularly implementations of the display and selection components, participants expected that realism would be compromised by increased accessibility. For example, tap was perceived as more realistic than console or ray-cast, but it also required that the user reach and stabilize their arm to perform the selection. Although accessibility and realism were identified as a trade-off for some individuals, this trade-off did not exist for others. For instance, P8, who assumed that he could use gaze input, preferred tap because it was realistic and accessible if he could trigger the tap animation with his gaze. Therefore, trade-offs were made based on participants' individual abilities and preferences.

Although participants discussed most of the design considerations that we identified before designing our Nearmi implementations, they also identified new ones that we did not consider, including (1) input device, (2) VE aesthetics, and (3) uniqueness to VR. P8 and P13 evaluated techniques in terms of their input device of choice, an eye tracking device. The Nearmi framework does not assume a particular input device and so its implementations should factor in the use of diverse input methods. With regards to the VE aesthetic, some participants commented that the aesthetic of some component implementations was not consistent with the VE theme that we used in our videos. For example, even though one participant felt that the ray-cast selection would be accessible, he thought the sci-fi aesthetic of the technique clashed with the occult theme of the VE.

Some participants preferred components that had qualities that were unique to VR. We called this design consideration "uniqueness to VR". For example, one participant preferred wand selection because it enabled him to see the representation from multiple angles, as if it were a hand-held object. Although his preference might be related to realism, we decided not to categorize it as such. One appeal of VR is that you can do things that you cannot do in real life and experience it in a similar way. P8, who had quadriplegia, wanted to watch an animation of his virtual hands not because it emulated reality, but because it allowed him to experience an alternative reality, which would not be possible with other technologies.

7.2 Need for Customizability in the Design of VR Techniques

Our findings highlight the need to consider the diverse abilities possessed by people with limited mobility. For example, we could have limited the selection techniques to those that required the least arm movement, but as P4 explained, there are individuals with strong arm movement but limited dexterity, making interacting with joystick or controller buttons challenging. In addition to diversity within a user group, individuals can experience different mobility throughout the day and over the long term. As a result, customizability is not only important for accommodating different individuals, but a single individual at different times.

Although our selection techniques relied on a VR controller as an input device, it is important to note that alternative input methods such as voice and gaze could also be implemented as either input to trigger controller animations (as P8 and P13 assumed) or as new selection implementations. For example, a gaze-based selection implementation could require users to dwell on POI icons to trigger the transition. Developers could create Nearmi implementations that take advantage of eye-tracking, voice recognition, and other input methods once they become commonplace on commodity VR devices.

Our findings illustrate that accessible VR hardware is not enough, software should also be accessible, which can be achieved through customizable design. In P15's words, "*I would hope that tech companies not only develop controllers and adaptive parts and stuff, but also think about if we are making a game, is it inclusive?*" (P15).

7.3 Customization and Personalization vs. Standardization in VR

VR is in an early phase as a mainstream consumer technology. As a result, hardware differs across VR systems, and interaction techniques differ across apps. The lack of standardization across hardware and software is likely related to the fact that VR experiences can be evaluated on so many criteria that an optimal technique varies depending on contextual factors (e.g., the VE, the goal of the app, etc.). In VR, design considerations like comfort and immersion are as important, if not more, than speed and accuracy.

Although standardization was a goal for technologies in the past, personalization now makes it possible to dynamically select interaction techniques based on users' characteristics. Numerous VR interaction techniques have been designed in the past 30 years and the number of available techniques will continue to expand as researchers continue to develop new approaches [44]. VR could benefit from the diversity and quantity of interaction techniques afforded by customization and personalization, rather than focusing on standardization. Accessibility could then be another design consideration alongside realism and comfort, for example, that would factor into selecting an appropriate technique. As a result, VR techniques might not need to be modified for the sole purpose of accommodating users' functional impairments as assistive technologies have done in the past [42]. Instead, there could be numerous reasons for a user to adopt an interaction technique, one of them potentially being accessibility. This paper advances the potential of customizability to guide future VR interaction design.

7.4 How Do We Evaluate Accessible VR Techniques?

If personalization and customization are goals for future VR systems, designers must establish a set of criteria for evaluating interaction techniques. Doing so would make it possible to match a user's preferences and abilities with the appropriate interaction techniques. For example, if a user was not sensitive to simulation sickness, they could use techniques that were highly immersive compared to more comfortable techniques that provided less immersion. Although established guidelines for evaluating accessible VR technologies do not yet exist, the design considerations that were surfaced in this study could be applied to any VR interaction technique (e.g., locomotion, object manipulation, etc.), not just POI techniques. Our study is a first step towards identifying factors that are important to users when evaluating accessible VR techniques.

Our study reveals that not only do we need to understand individual design considerations, we also must understand the relationships between considerations in the form of trade-offs. Al Zayer et al. [44], identified design considerations that were consistently related for different types of locomotion techniques. However, accessibility was not one of the factors considered. Therefore, the trade-offs identified in that paper might not hold for techniques that are designed to be accessible, which highlights the need to establish a set trade-offs when accessibility is thrown into the mix. We hope that designers will not only continue to invent accessible VR interactions, but also discuss the rationale for the criteria they choose to design and evaluate their technique with. In this way, our community can move towards a better understanding of how to make VR accessible and engaging at the same time.

7.5 Limitations and Future Work

We designed our study so that it could be conducted remotely due to the COVID-19 pandemic, even though our Nearmi implementations were ready to be used by participants. While our results are still valuable for understanding how people with limited mobility would evaluate accessible techniques before trying them in VR, a user study in which participants complete tasks in VR would reveal in-depth information about the trade-offs we identified in this study. However, because people with mobility impairments watch other people use VR before investing in it (section 6.1.2, [43]), it is still critical to understand how they evaluate VR techniques in the pre-adoption stage.

Feedback from participants pointed to several potential directions for future work, such as incorporating other input modalities (e.g., gaze). Another design challenge that could be addressed in future work is introducing a customizable technique like Nearmi in a way that participants can create their preferred implementation without going through multiple permutations. This could be achieved by using AI to narrow down the set of implementations presented to the user based on data about their abilities and preferences. Finally, future work can facilitate developers' use of the framework by creating a toolkit with POI prefabs that developers can place in the environment.

8 CONCLUSION

We presented Nearmi, a design framework for creating accessible POI techniques for people with limited mobility. We made two additional contributions (1) a set of design considerations identified by participants when choosing their preferred Nearmi implementations (2) participant feedback on the subset of Nearmi components we implemented. Our findings highlight the trade-offs that participants made when choosing a preferred implementation of Nearmi, and they suggest the need for customizability to accommodate diverse abilities and preferences. Our study contributes to a growing research community that aims to make VR usable people with disabilities. As adoption of VR increases, our community not only needs to develop accessible interaction techniques, but also establish the key criteria for evaluating them.

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