Near and Far Interaction for Augmented Reality Tree Visualization Outdoors

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Abstract: The implementation of augmented reality in nature and in an environmental education context, is not a common case. Furthermore, augmented reality is often used basically for visualization, which puts users in a rather passive state. In this paper we investigate how near and far interaction using a head-mounted-display can be combined with visualization on a tree outdoors and which of the interaction techniques are suitable for a future use in an environmental education application. We examine the interaction with virtual leaves on the floor combined with a virtual-real interaction with a real tree. Parameters like type of interaction, different real surroundings and time task performance, as well the interplay and connection between them are discussed and investigated. Additionally, process visualization in a nature setting like clouds and rain, and growing of tree roots are included in the augmented reality modules and evaluated in user tests followed by a questionnaire. The results indicate, that for a future educational application both, near and far interaction, can be beneficial.

1 INTRODUCTION

Environmentally responsible behavior and its development depend on many different factors. The interplay of knowledge about the natural environment and outdoor experiences, for example, are mentioned by Ernst and Theimer in their literature review (Ernst and Theimer, 2011). With augmented reality (AR) the environment can be enriched with additional information, visualization and interaction possibilities. Azuma defines three conditions for AR: the real environment must be combined with virtual objects, there must be interaction in real time, and registration in 3D (Azuma, 1997). Augmented reality is often used in education, but its implementation *outdoors*, *in nature* and in an *environmental education context*, is not a common case (Rambach et al., 2021) and there is still a need for more research in this area. Furthermore, augmented reality is widely used basically for visualization, which puts users in a rather passive state.

For a more interactive setting we examine the different interaction possibilities with an HMD (head mounted display), in a use case scenario outdoors in the nature. We discuss the advantages and disadvantages of *near* and *far interaction* techniques with regard to the special outdoors setting. The discussion is based on results we obtained from specially designed user tests with an educational background.

The developed AR modules can be adapted and integrated into different educational scenarios. This can be done, for example, in the context of *green school* programs on topics such as forest knowledge, ”creatively experiencing the forest”, soil, and the connection between weather, climate and trees. The modules can also be used during guided hikes, with special stations in the forest where environmental AR games are offered, or during action days for innovative forms of environmental education.

A HoloLens 2 is used for our augmented reality (also noted by Microsoft as mixed reality (Microsoft, 2021a)) modules. In particular, we study the different task performance of *near* versus *far interaction* in a *tidy and even-leveled* versus a *more natural* environment.

2 RELATED WORK

Prior research compares interaction techniques in AR and shows their value in different use cases. Nizam et al. present an empirical study of key aspects and issues in multimodal interaction augmented reality

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(Nizam et al., 2018). They found out, that the modality getting the most attention is the gesture interaction technique. In another paper, Chen et al. are exploring the possibility of combining two input modalities, gesture and speech, for enhancing user experience in AR. In their application the example of interacting with a virtual dog is fulfilled by using predefined marker, Leap Motion controller for gestures and Google Cloud Speech API for speech interaction (Chen et al., 2017). Their results show that both, gesture and speech, are effective interaction modalities for performing simple tasks in AR.

Some works compare direct and indirect interaction, either gesture combined with speech (Piumsomboon et al., 2014) or, e. g., Lin et al. investigate direct interaction versus interaction with the use of a controller (Lin et al., 2019). In other works, two-handed gesture interaction is evaluated with focus on rotation and scaling (Chaconas and Höllerer, 2018). In contrast, our work compares near and far interaction for selection and translation tasks in different environments in nature.

The efficacy and usability of AR interactions depending on the distance to the virtual objects are discussed in the work of Whitlock et al. (Whitlock et al., 2018). The used device (AR-HMD Microsoft HoloLens 1) is combined with a Nintendo Wiimote as an additional handheld input device. They concluded embodied freehand interaction to be the user's highly preferred choice of interaction. They explored distances reaching from 8 to 16 feet (2.44 m to 4.88 m), which can all be considered as far interaction and do not include the near interaction that we also observe.

Recent work (Williams et al., 2020) focused on understanding how users naturally manipulate virtual objects based on different interaction modalities in augmented reality. These manipulations consist of translation, rotation, scale and abstract intentions such as create, destroy and select. A Magic Leap One optical see-through AR-HMD was used in this experiment. They found out that, when manipulating virtual objects, using direct manipulation techniques for translations is more natural. This is also the type of interaction that we investigate.

Others compare different interaction metaphors (e. g. Worlds-in-Miniature) that can also be seen as near and far interaction (see e. g. (Kang et al., 2020)). Some previous work has even attempted to fuse near and far interaction into a single interaction metaphor (Poupyrev et al., 1996). However, none of this previous work considered an outdoor environment in nature.

Recently, we conducted an outdoor study (Lilligreen et al., 2021) regarding rendering possibilities and depth impression for an AR visualization in nature context, but there was no focus on interaction like in the presented work.

3 AR APPLICATION DESIGN AND IMPLEMENTATION

In this section, we give an overview of our AR application, the implemented interaction techniques and the developed visualizations for outdoor usage in nature on a tree. A user centered design approach (Gabbard et al., 1999) has been applied through the development of the educational AR modules. After meetings and interviews with experts in the area of environmental education and augmented reality, personas and user task scenarios were developed and later modified through the development cycles. The main target groups for the AR modules are:

- experts in environmental education, that want to use innovative solutions for nature and environment
- people interested in nature
- "digital natives" who prefer learning with new technologies

Depending on the target group, the AR application can bring different benefits. People, interested in nature can learn in a new way and e.g., explore hidden things in the forest. On the other hand, people, interested in technologies can be motivated to learn more about nature. First user tests (Lilligreen et al., 2021) were helpful for the visualization of underground AR, that is part of the module "growing roots" (see section 3.2). User tests regarding the interaction in outdoor scenarios are discussed further in this paper.

3.1 Interactive AR Modules Outdoors

As we want to investigate how people interact in an outdoor scenario, we developed interactive AR components focusing on the example tree. These components are described in the following.

3.1.1 Touchable Tree

The appearance of virtual leaves is triggered by touching a real tree stem (see figure 1). Leaves from different tree species fall to the ground around the tree. This virtual-real interaction makes the connection between the real environment and the AR visualization stronger, as this is one of the goals for using AR by definition. Without any connection to the real-world virtual reality could be used for visualizing objects.

We used a draggable virtual stem to decide on which real tree to show the visualization. Here, the first idea was to use the surface magnetism solver (Microsoft, 2021d) to position the visualization. This would be a good choice for displaying objects on walls or floors as they appear automatically and ”stick” to the walls. In the context of nature most objects do not have flat and big surfaces and therefore the surface magnetism does not work well. We decided to let the virtual stem be manually and thus more precisely positioned by an advanced user, which could be a teacher in educational context or an organizer of nature educational excursions. After positioning the virtual tree on the desired real one, the teacher confirms and the virtual stem ”disappears”. Technically this happens by using a shader that renders the stem invisible. The virtual tree is not draggable anymore but can be used to show virtual leaves on the ground. The user (a student, in the educational context) can now touch the tree and virtual leaves fall to the ground.

Figure 1: By touching the real tree virtual leaves fall to the ground.

3.1.2 Collecting AR Leaves

After touching the tree over 30 virtual leaves (three different types) fall to the ground (See figure 2). The leaves are mixed and appear around the real tree. The users can grab the leaves using direct manipulation with their hands, which is recognized by the HMD (HoloLens 2 (Microsoft, 2021b)). We refer to this type of interaction as *near interaction*. The users can then carry them to a virtual bucket, which also appears next to the tree. By putting a leaf in the bucket, a timer and a counter are activated and the users can see the time and count of leaves above the bucket. The second possibility to collect the virtual leaves is by using the *far interaction* (sometimes called ”point and commit with hands” (Microsoft, 2021c)), which is also realizable on the HMD used (Microsoft, 2021c). Here, a ray, coming from the hand is used to select the leaf and then with the grab gesture known from the direct interaction the object can be moved. The exact scenario for the user tests is explained in detail in section 4.1.

Figure 2: Different types of leaves lie on the ground and can be collected in a bucket.

3.1.3 Clouds and Rain

Another interactive AR module in our application, inspired by nature, shows virtual clouds a couple of meters away from the tree. These clouds (rendered in low-poly style) can be dragged by the users using *near* or *far interaction*. When moved to the tree, virtual rain starts falling from the clouds. For the visualization of the rain, we combined several particle systems in the Unity engine (Unity, 2021).

3.2 Visualization of Natural Underground Processes in the Forest

To exploit the AR advantage of making the invisible visible in nature, we developed two AR visualizations, which are part of the AR application for the user tests. The modules are described next.

3.2.1 Underground Water

After starting the rain by dragging the clouds, underground water molecules are visualized with blue spheres (See figure 3). The spheres are animated and shrink over time to disappear in the soil and the tree root. A particle systems is used to realize this effect.

3.2.2 Growing Roots

The biggest hidden object in our case is the tree root. We used a 3D model which extends three meters in each direction starting at the tree stem. To show the growth we animated a root string using the computer graphics software Blender (Blender-Foundation, 2021). The animation is played in a loop,

Figure 3: Part of the tree root and blue water particles.

so the user can watch it more than one time. The animation starts when the rain begins to fall. Because in nature there are trees of different sizes, an adjustable size of the roots is necessary. We provide functionality for scaling to the model and the users can control the size incrementally with voice commands (“bigger”/“smaller”).

3.3 Indoor vs. Outdoor

During the development cycle we completed tests indoors and outdoors and compared them. For example, in the beginning flat leaves were used for the collecting task. This was pretty easy indoors, but quite difficult or uncomfortable outdoors. Some users could not grab the leaves. To ensure that the leaves can be collected easier, also on uneven areas outdoors, we provided the leaves with (invisible) colliders a couple of centimeters bigger with respect to the y axis. This way our modules can be also used in an area covered with grass and small branches. Additionally, if the soil is wet after rain, it could be uncomfortable for the users to touch it when using direct manipulation. With bigger colliders, they can still grab the virtual leaves almost naturally but do not have to get their hands wet.

Regarding depth perception and the visualization of underground objects like the tree roots, a recent work (Lilligreen et al., 2021) investigated different rendering possibilities using virtual holes and different textures in an outdoor scenario. They found out that the quality of the depth perception using an HMD is already on a very high level due to the availability of stereo rendering. We decided to display the tree root without additional masking so it could be seen in its whole size. In an indoor location this would be not very convincing as usually there is less space and the context of nature would be missing.

For the visualization of the rain outdoors, we used brighter colors because outside there is more light and the raindrops merge with the background more then in an indoor location.

A location outdoors in the nature can be more dynamic than an indoor location. Light changes can appear depending on the weather or the season. Unplanned changes in the environment like fallen branches or too high grass could also hinder the usage of the application on a particular tree. Therefore it could be necessary to choose a tree spontaneously – with sufficient shade or enough space around the tree. To enable more flexibility we built in functions for scaling the tree stem and roots in the AR application with the usage of speech commands. Furthermore a teacher can choose between tree types, so that different virtual leaves can be selected according to the situation on site.

4 METHODS AND EXPERIMENTAL DESIGN

In this study we applied a formative evaluation to examine *near* and *far interaction* in AR with small and bigger objects in two different nature settings outdoors. Task-based scenarios were developed in order to compare the different interaction techniques in the different natural surroundings. We were interested in user impression of the two variants of the interaction technique, the task performance using the different interaction techniques and in usability issues. We assumed that each technique had advantages and weaknesses.

4.1 User Tests

For the conduction of user tests outdoors the climate conditions are very important. We chose days without rain and snow, so that the hardware can be used easily. Although we have performed the tests in the summer, some appointments had to be postponed due to rain. The time periods were in the morning or the early afternoon in order to ensure that the light conditions are suitable. The tests were made under a tree, so there was enough shadow, that an optical see through device could be used also on sunny days.

At the beginning the HMD was calibrated for the current user. This way the precision for the interactions is increased. During the tests we observed the participants and took notes when they commented on the application.

Using the module “Collecting AR Leaves” (Sec. 3.1.2) we measured the user task performance. We chose task completion time as a metric since this is a commonly used metric for evaluation of interactions in virtual and augmented reality (Samini and Palmerius, 2017). The participants stood under an oak tree and had to collect five oak leaves and put them in a virtual bucket next to the tree as fast as possible. They had to choose from three leaf types – birch, oak and maple. In a *preparatory stage*, the users tried the different techniques, which had been explained to them before the test started. The *first task* was to collect the virtual oak leaves using the direct manipulation with hands (*near interaction*, see figure 4 top). The *second task* was to collect the leaves using *far interaction* (See figure 4 down). The different times it took users to complete the tasks were saved. Collecting of virtual leaves was selected as a task to compare the different interaction possibilities. The overall scenario described so far was chosen for two reasons. First, an AR outdoor study (Lilligreen et al., 2021) focused on depth perception found that context plays an important role – e. g., users rejected a visualization of a grid over a virtual hole to enhance depth perception in the forest because a grid is not what would be expected in nature. Leaves are part of the forest and collecting them during a walk is not an atypical action. Second, a task to collect only a specific type of tree leaves can be used in a learning scenario.

Figure 4: The two investigated interaction techniques. Top: Direct manipulation with hands (near). Down: Point and commit with hands (far).

Each user had to perform the described test two times. The first location was in a *tidy and even-leveled area* in a park alley, under an oak tree. The second test was in a *more natural area* with grass and branches under another oak tree. This way we wanted to compare also the times of the tasks in different types of outdoor environments.

Another task for the participants (to be performed at both locations) was to move virtual clouds to the tree. Then a virtual rain starts to fall as described in Section 3.1.3. The water molecules appear under the ground and a branch of the tree root begins to grow. Similar scenarios can be used in an educational setting to show hidden processes in nature or e.g., to introduce a topic about a drought caused by climate crises and the connection with trees and roots. The participants had to observe and comment what they see and after the three tasks, they had to fill in a questionnaire, which is described in Section 4.4.

4.2 Working Hypotheses

We defined some working hypotheses which are described next.

H1: There will be a difference regarding performance between *near* and *far interaction*.

We assumed that the two interaction methods will perform differently. From first short tests we noticed, that different people had a different preferred method. To investigate this, the time performance had to be compared and in the questionnaire there were statements for subjective preference.

H2: Older participants (55 and older) will prefer using far interaction.

Around 1/3 from the test users were 55 or older. We thought that the bending to collect items from the ground could be uncomfortable or tiring over time, especially for older people. Therefore they could prefer to collect the items from distance using the far interaction method with a ray.

H3: Users will be faster in a tidy, even-leveled area.

When comparing the performance in the two locations, we assumed that in a flat area, where the users can walk easier and the ground is even they would need less time to perform the task (collecting virtual leaves). Also, the grasping of the leaves should be easier when no or at least less real objects are on the ground.

H4: For more participants near interaction for collecting items would be easier.

We predicted, that near interaction for collecting objects would be more natural and easier, as this type of interaction is more similar to the real-world grasping and the users are more familiar with that, then with the interaction using a ray from a distance.

Table 1: Participants characteristic – age.

Age: years	Count (%)
< 20	2 (10%)
20 - 29	4 (20%)
30 - 39	1 (5%)
40 - 49	6 (30%)
50- 59	3 (15%)
> 60	4 (20%)

H5: In a more natural area, the far interaction will be preferred rather than the near interaction.

In contrast to H4 we raised the question if the type of environment plays a big role. We assumed that in wilder environments people would prefer to interact from distance instead of touching the real grass, leaves, branches or to walk between bushes to reach an object. Furthermore, when the participants get more familiar with the far interaction, they could prefer it, as this way they do not have to move too much and could be faster.

4.3 Participants

A total of 20 people (2/3 male, 1/3 female) participated in our user tests. The youngest user was 10 years old, the child was accompanied by his parent, who gave permission to perform the experiment. The oldest user was 78, the average age was 42 years. The age distribution is listed in table 1.

The results of our test are intended to be useful for an educational module in nature. Therefore, we focused on two types of participants - people which work or are very interested in nature and environment (11 participants) and users, which already have first experience with AR or study/work in the area of computer science (9 participants). This way we collected opinions from the first group that can represent teachers or organizers of educational excursions in the nature. Some of these participants work in nature organizations or in the area of environment and plants. The second group can be representative for student groups or digital natives which enjoy working with technical items.

4.4 Questionnaire

A questionnaire (See figure 5) completed by the participants after the user tests, helped to obtain further information and to capture the subjective experience of the participants. We adopted and adjusted statements from SUS (Brooke, 1995) and NASA Task Load Index (Hart, 2006). The first part of the questionnaire was completed directly at the first testing location. The remaining questions were answered at the end of the whole user test. Questionnaire metrics, that can be considered for measuring usability (Samini and Palmerius, 2017) are integrated in our statements e. g., ease of use (S2, S6), comfort (S2, S3, S6, S7), enjoyability (S4, S8) or fatigue (S3, S7). An expected problem regarding the translation of virtual objects is the "gorilla-arm" effect (Jerald, 2015) when moving a lot of objects using near interaction and holding the arm high. This can cause fatigue and reduce the user comfort.

Module „Collecting AR Leaves"

		Fully agree	Agree	Neutral	Disagree	Strongly disagree
1	I was able to find the wanted type of leaf pretty quickly.					
2	Picking up the leaves **directly** with hands was easy after a short period of familiarization.					
3	Picking up the leaves **directly** with hands was tiring after a while.					
4	Picking up the leaves **directly** with hands was fun.					
5	I think I was pretty good at completing the task (picking up **directly** with hands).					
6	Picking up leaves from a **distance** (with the ray) was easy after a short period of familiarization.					
7	Picking up the leaves from a **distance** (with the ray) was tiring after a while.					
8	Picking up the leaves from a **distance** (with the ray) was fun.					
9	I think I was pretty good at completing the task (picking up from a **distance**).					

Figure 5: Statements from the questionnaire for the *collecting leaves* task (lower rows for the *natural area* marked with a graphic of leaves).

We also integrated an additional free text question ("You triggered the falling of the leaves by touching the real tree trunk. How did you perceive this real-virtual interaction?") to obtain more qualitative data.

5 RESULTS

Regarding the task completion time and our hypotheses H1 and H3, the average time from all finished tests was calculated for the four combinations of interaction techniques and locations (See figure 6). The participants were faster at the more natural location, which was also the second location. Between the near interaction (collecting directly with hands) and the far interaction (using the ray to select) there was a difference of approximately two seconds – the participants were slightly faster when they collected the leaves directly with their hands. It is also to mention that some of the older participants had problems to collect the virtual leaves and could not finish the time-based tasks. These were excluded from the calculation of the results.

Another result which was not the assumed one (H2), is that older participants slightly preferred more

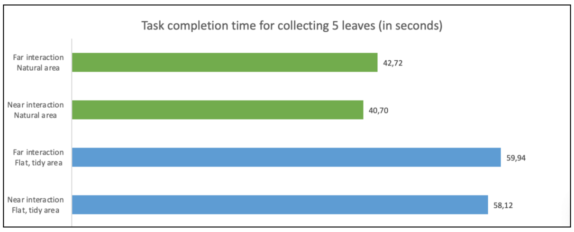

Figure 6: Results for the average task completion times for collecting 5 leaves (in seconds) with the different interaction techniques at the different locations.

the direct collecting of the leaves. Here, the more natural interaction is to some extent stronger than the benefit of not needing to bend and walk.

According to the data from the filled questionnaires (See Table 2) and after reading and analyzing the observation notes we can state, that our assumption, that users will find the direct interaction technique easier (H4) is not correct. The results for both techniques (near and far) show minimal difference.

Table 2: Results for the statement: ”Picking up the leaves was easy after a short period of familiarization.”.

	fully agree	agree
near interaction in tidy area	8	5
near interaction in natural area	10	6
far interaction in tidy area	8	7
far interaction in natural area	10	5

Observing the results, it is apparent that no substantial difference appears between the far and near interaction in a natural area (H5). For the near interaction the mean value was 4.3 with SD = 0.78, for the far interaction the mean value was 4.05 with SD = 1.20. 3/4 of the users agree or fully agree that both were easy – collecting the leaves with far (15 persons) and with near (16 persons) interaction.

Regarding the factors of enjoyability and fatigue it is to mention, that most users agree or fully agree, that it was fun to collect leaves using near and far interaction and that each interaction is not tiring.

Considering the the free text question about how users perceive the real-virtual interaction with the tree, 65 % of the participants have given positive comments e.g., “surprisingly real”, “The interaction was intuitive as it established the connection to reality and thereby slowly introduced to the AR world”, “a great experience”. One third of the users could not see the falling of the virtual leaves, they saw them lying on the ground already. The small field of view of the HMD could be a reason for this. Additional visual feedback or longer, respectively more slowly falling leaves can improve the perception.

6 DISCUSSION

With this work we provide some valuable insights in the usage of near and far interaction techniques in a nature context. This way, we address the need for more research about the usage of AR in the area of nature and environment.

The difference between the two investigated interaction possibilities – near (direct with hands) and far (with a ray) is not substantial regarding the ease of use. It was observed that it seems to be a subjective choice according to the preferences of the users. In some cases, only one of the interaction techniques functioned good. Some participants moved their hands too fast or too slowly while “pinching” the leaf and it seemed as if the calibration process at the beginning was not fully precise. The interaction with the ray was to some extent untypical and not intuitively understandable for some of the participants. For these reasons we recommend for future applications to include both interaction options.

The results from our user tests regarding the different environments indicate other than expected, that users were faster when interacting in the natural area. The uneven ground, covered with grass and branches did not affect the speed of collecting leaves. It was observed that some participants move grass with one hand to reach the virtual leaves, but the provided bigger colliders for the virtual leaves seem to be a good and efficient way to deal with the outdoor conditions. Additional explanation for this result can be the fact, that for the second test at the natural area, the users have gotten used to the interaction techniques and were a little faster. More research with different settings and with more AR experienced users might be useful to get a more comprehensive result.

The underground visualization was fascinating for the participants, which increased the enjoyability factor. But in a future application the growth of the tree roots should be demonstrated on the whole root structure (and not only on a branch) in order to be directly visible.

7 CONCLUSION

In this paper we investigated the usage of near and far interaction using an HMD at two different types of locations in nature. We developed AR visualizations for the example of a tree and used them in interactive educational scenarios. This way, we explored how users interact in a natural-virtual constellation and gained understanding in usability matters or preferences for a particular interaction technique in an outdoor usage. We investigated the interaction techniques on the example of virtual leaves, clouds and with a real tree. A slightly better task completion time was measured when using the near interaction technique (see section 5). However, further work and different cases are needed to provide more general conclusions for an outdoor usage. We observed that the users enjoyed the different tasks and highlighted that a usage in a future educational application can benefit from both – the near and the far interaction.

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