A Mixed Reality Environmental Simulation to Support Learning about Maritime Habitats

An Approach to Convey Educational Knowledge With a Novel User Experience

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ABSTRACT

Environmental simulations allow for an easy and safe acquisition of knowledge about hard-to-reach habitats. We present a mixed-reality simulation that enables the user to convert (parts of) an arbitrary place like his or her own living room into a maritime habitat, using the example of the Baltic Sea. The user explores the virtual underwater world by walking in the real world. Typical characteristics and elements of the simulated habitat are integrated by adjusting light refraction and textures, and by adding animals, plants, and stones. The virtual animals respond to the user's movement. Rearranging real world objects causes the virtual world to change its appearance as well. User tests show that the environmental simulation provides an authentic insight into the Baltic Sea habitat and is well received with regard to the overall user experience. However, for first-time users, conveying more formal knowledge does not seem to work as well (yet) as compared to a conventional textbook approach.

CCS CONCEPTS

• Applied computing → Interactive learning environments • Human-centered computing → Mixed / augmented reality

KEYWORDS

Environmental simulation, mixed reality, augmented reality, ecosystem, habitat, computer-supported learning, swarm simulation, 3D scanning, lighting, texturing

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1 Introduction

One advantage of environmental simulations is an easy and safe knowledge acquisition [1]. This offers a chance to explore habitats that would be hard to reach in reality. Although a simulation is usually technically restricted and cannot be completely replace the interaction with the real environment, it provides an opportunity to reflect, visualize, bundle and highlight specific educational knowledge in a simplified manner. In this work, a simulation system is presented that uses a mixed-reality approach to support education about ecosystems. As the sea is an important part of the climate system and biodiversity [2] and underwater worlds are one of the hard-to-reach places that most people are not familiar with, we focus on maritime habitats and choose the Baltic Sea as an example.

The goal of our simulation is to impart the atmosphere and typical characteristics of the Baltic Sea through an explorative user experience focusing on flora and fauna. Unlike with conventional, passive media like textbooks or films, it is possible to interact with the environment and the users have the freedom to explore the environment according to their own interests.

To allow for a more diversified and potentially more stimulating experience, we chose a mixed-reality approach that allows the user to convert (parts of) an arbitrary place like his or her kitchen or living room into an underwater world. A pure virtual reality approach would not allow doing this, as the user would be completely shielded from the real environment.

2 Methods and Material

The simulation system uses a Microsoft HoloLens. The HoloLens allows gathering information about the real environment and the user's position and is fully self-contained, i.e. does not require any external computers. However, the computing power of this device is limited as compared to virtual reality devices that use a stand-alone computer (e.g., HTC Vive or Oculus Rift), making it more challenging to provide a realistic environmental simulation, especially with regard to the visualization. The software for the simulation has been developed using the game engine Unity.

When the user has put on the HoloLens glasses and has started the application, the real environment he/she is currently in is converted into an underwater world (Fig.1). Fig. 2 illustrates the different components of this conversion. The user can choose a tutorial mode where these conversions take place step-by-step (Fig. 3) accompanied by oral narrative instructions from a virtual guide ("voice-over").

As interactive element, objects like furniture (Fig. 4) can be moved during the simulation, which leads to recomputation of the simulated environment (e.g., a chair or trashcan that turned into a stone can be placed somewhere else and will again be turned into a stone). In addition, the simulation contains virtual fishes that react to the user's movement according to their natural characteristics (e.g., hiding in the sand, or fleeing), including some basic swarm behavior. To allow for acceptable frame rates on the target hardware of the HoloLens, the models generally consist of a relatively small number of polygons ("low poly").

Independent of the tutorial mode, additional information is provided to the users through the voice-over when they look at an object of their interest for a longer time, e.g. about swarm or eating behavior of a fish or the oxygen production of a plant. For each object, multiple pieces of information are available, so that something new is explained when an object is targeted again.

The following sections 2.1-2.3 describe details of the conversion and simulation.

2.1 Transformation of the environment

Our application queries the sensors of the HoloLens (a depth camera, an ambient light sensor, and a conventional video camera) to calculate a virtual 3D representation ("world-mesh") of the user's real environment, obtaining information for a cubic meter every second. The floor is replaced by sand, walls are replaced by stone, and the ceiling is cut off to reveal the ocean surface (Fig. 1c). When trying to calculate the distance from floor to ceiling, special care has to be taken with possible inconsistencies in the scanned world-mesh like holes or stray vertices. The height values of all vertices with normal vectors pointing upward and downward are recorded for the lower and upper half of the world-mesh, respectively. By taking the median of both sets, the height-level of floor and ceiling will be calculated while ignoring misleading vertices. With the floor and ceiling defined, a shader program decides whether to draw a pixel of the rasterized world-mesh as sand lying on the floor or to make them transparent to have the ocean surface replace the room's ceiling. Pixels not considered as floor or ceiling are drawn with a set of stone-like textures. This has the advantage of real environmental boundaries blending into the scene naturally. Several textures are mixed to create a more varied and naturally looking environment.

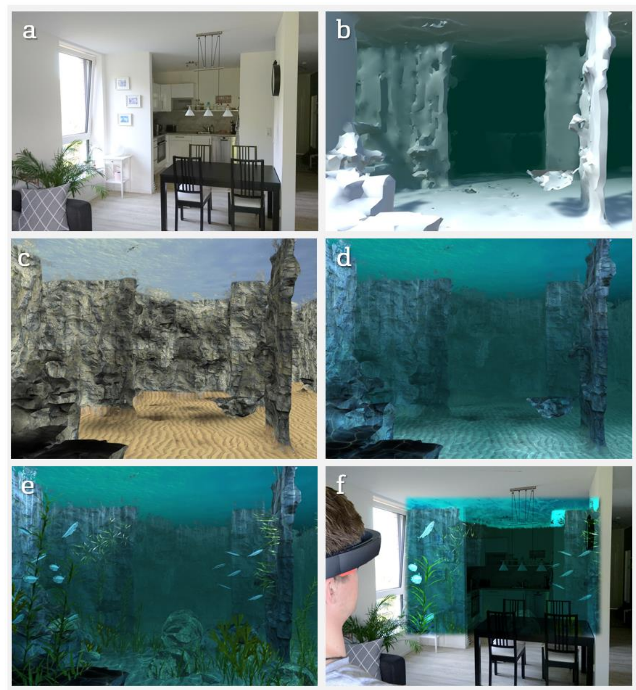

Fig. 1: Creation of the mixed-reality world: a) the user's real environment b) the reconstructed surface of the real environment c) virtual models based on the reconstructed surface (using textures) d) with underwater lighting simulation e) with added animals and plants f) illustrating the user's perspective.

2.2 Adaptation to underwater characteristics

In order to present the simulated environment convincingly, typical characteristics need to be included [3][4]. This includes simulating the vision under water with filtering and refraction of light (Fig. 1d). The sunlight is refracted on the ocean surface and reflected on the walls and on the ground. In addition, the energy of the light decreases with increasing depth depending on the wavelength, so that colors are gradually lost through selective color extinction. The longer the light waves are, the less energy they contain which is why the respective color is lost earlier. Already at a depth of five meters only about five percent of the red part of the light at the surface is still present, which is why red objects seem to lose their color and appear brown to almost gray. With increasing depth further part of the light are decreased which leads to a remaining blue-green color impression.

The light processing starts by approximating diffuse sky radiation caused by Rayleigh scattering of sunlight using a strongly blurred image of an outdoor environment. Linear interpolation between the world-mesh's floor and ceiling levels is then used to tone down the colors depending on how close the processed pixel is to the floor. Next, a series of images showing light scattered by ocean waves is projected downwards onto the world-mesh. Water in the Baltic Sea is never completely clear: It is diffused by phytoplankton, sand whirls, and fine pieces of algae. This results in turbidity, which is simulated by particle effects and distance-based color grading.

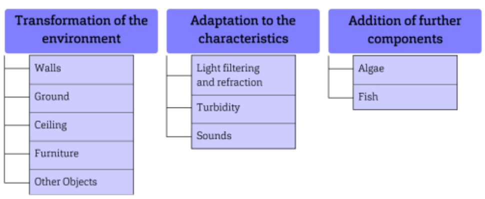

Fig. 2: Overview of the adjustments to the environment

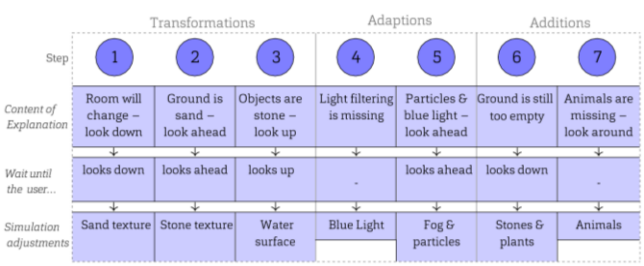

Fig. 3: Steps in the tutorial mode

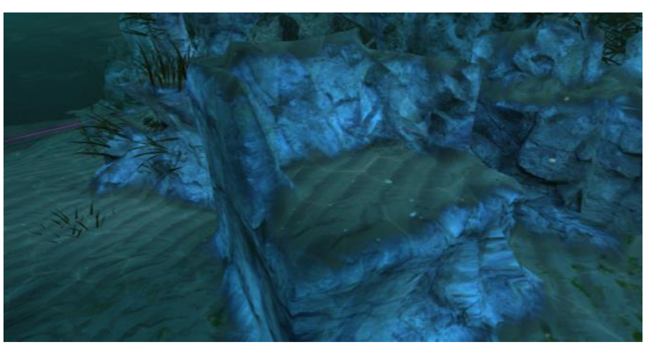

Fig. 4: A real-world chair becomes a stone structure in the virtual underwater world.

Since the acoustic background noise of the real environment cannot be suppressed, it is possible to hear ambient noise that does not belong to the actual simulation which might affect the user's immersion. The HoloLens has built-in speakers, which are used to support the experience with sound and ambient music. The speakers direct the sound towards the ears, which makes it possible to hear both the real and the virtual environment. The sound of moving water is one of the essential features of an underwater environment, thus a sound clip of moving water is continuously played. This sound provides an acoustic feedback on the user's movement as the volume depends on the user's speed.

2.3 Addition of further components

Groups of virtual models of algae and bladderwrack are randomly placed on the floor and the walls of the scene, as these are important parts of the Baltic Sea. Additionally, shells and crabs are placed at random locations.

The Baltic Sea is characterized by relative poverty of species with high numbers of individuals. Representing the two most common species, virtual models of Baltic herring and plaice are also added to the scene. Their behavior is simulated by a particle system, which includes swarming, food intake, and flight. The boids algorithm [6] is used to implement the swarming behavior of the individual fish schools. Each fish moves independently based on its position in the world-mesh and its distance to other fish in the school. The boids algorithm is only used to simulate the schooling behavior of a large group of fish. To represent a more complex behavior, like feeding, other types of fleeing, and spawning, a finite state machine was introduced. This state machine defines what happens under certain conditions, like a specific area a school roams or a specific distance to the position of the user and predators. Should these conditions apply, a transition takes place between the current state and the one the fish needs to change to. While transitioning, the necessary changes are made to fit the behavior of the target state. The fish school then behaves differently depending on the current state. The differences vary from schooling density, fish perception up to a change to a shoaling behavior.

In addition, the fish need to react to simulated environment based on the world-mesh. If the distance of a fish to the world-mesh is below a certain threshold, a 3D vector pointing in the opposite direction of the vertex is applied as a force to the individual fish. This force gets stronger the closer a fish gets to the wall. As computing this distance for each vertex of the world-mesh for each single fish is too time-consuming on the target hardware, a grid approach was introduced [7]. It separates the 3D space into smaller cubes, i.e. grid cells, and limits the perception of a single fish to its current grid cell.

3. Evaluation

We performed an evaluation with 20 users, who were randomly separated into two groups. Group A tested the mixed-reality-application in the tutorial mode. Group B read an educational article that contained the same information about the Baltic Sea as provided by the voice-over in the application. The knowledge of all users was evaluated before and after the test with a custom-made knowledge questionnaire, that contains ten questions about animals, lighting, turbidity and plants. To measure user experience in terms of attractiveness, visibility, efficiency, reliability, stimulation, and novelty, both groups completed a User Experience Questionnaire (UEQ) [5]. Furthermore, another custom-made questionnaire was used for group A to evaluate their opinions on the application. It contained questions about the introduction features (narrator, start sequence, step-approach), the interaction (with fish and environment) as well as the simulation parts (transformations, adaptions and additions, as shown in Fig. 2 and Fig. 3).

4. Results

The UEQ results show that both the textbook and the mixed-reality-application were evaluated as fundamentally positive. The application was rated with a higher attractiveness, perspicuity, stimulation and novelty, whereas the text was rated as more efficient and dependable (Fig. 5).

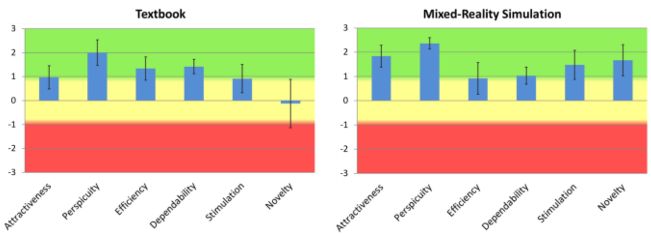

Fig. 5: UEQ results

The knowledge questionnaire shows that both groups improved after receiving information from the text or the application, with the improvement often being better with the text (Fig. 6). The text users had an average of seven correct answers per question, whereas the application users got an average of six-point-four answers right. Some participants from group A stated that they were so fascinated by the mixed reality simulation that they forgot to listen to the voice-over. Accordingly, they said after using the application, they had a better idea of the Baltic Sea but could not answer all the questions of the knowledge test. In contrast, the readers of the text were more concentrated and tried to absorb as much knowledge as possible.

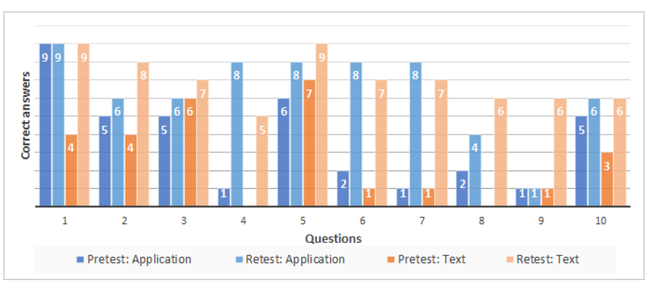

Fig. 6: Knowledge test results per question and group

The users of the application stated that they liked the underwater world, especially the plants, fish, and the sound, which provided a pleasant learning atmosphere. They considered the initial sequence to be helpful in getting used to the HoloLens glasses and in avoiding being overwhelmed by the simulation. The initial sequence had a pleasant speed to concentrate on individual aspects. Those aspects would be particularly noticeable and memorizable. Overall, the fish were perceived as authentic, with some users criticizing their behavior, and the others finding it to be natural. Some users wished to see a bigger variety of animals. The plants were perceived as well represented, it was positively noted that they move in the current and are numerous and varied. Some users noticed the general "low poly" style of the plants and animals but did not find it distracting. Interestingly, other users found them to be very detailed and convincing. When asked about interactions, several testers noticed that they felt "in the middle of it", and "it was fun to walk through the room and discover the habitat". It was noted as positive that when looking at animals and plants additional information was provided through the voice-over. The users also liked the attention to detail in the lighting conditions very much. They also liked the fact that the simulation could be influenced by moving furniture or other objects. Some of our testers mentioned that they were bothered by the small field of view in the beginning. However, they also stated that this effect faded after a period of familiarization.

5. Discussion

Even if the contents of the application were the same as in the text, the readers of the text achieved better results in our evaluation, with the main reason probably being that the users of the application often forgot to listen. It is important to note that users who are not yet familiar with mixed reality, this technique can generally have a distracting effect initially. Moreover, although conveying visual information (appearance, size, behavior, etc.) seems to work well in our application, the focus on visual information probably adds to the distraction from the more formal information that is presented by the voice-over. However, if the users have a special interest in an area and pay attention to the voice-over, we assume that the concerned knowledge can be easily conveyed. It is unclear which group would be able to remember information for a longer period of time. We would assume that the application users remember the visual impressions of the Baltic Sea longer than the other group, who only read a description. As compared to a textbook, a simulation can give a multisensory impression of what it means to be under water (without having to worry about oxygen supply), making it probably easier to remember. A long-term test will probably provide more detailed findings with regard to this aspect. In general, people might have different learning styles (visual, textual, acoustical), which was not considered in our test.

The results of the UEQ and our additional questionnaire show that the users of the mixed-reality application were more excited to experience this habitat. This could lead to users being more motivated to explore and learn more about it (potentially then also with conventional methods).

In conclusion, a mixed-reality simulation can give a stimulating insight into a habitat, despite several restrictions based on today's computer hardware, thus potentially leading to a more sustainable knowledge and interest as compared to conventional teaching methods.

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