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NEMO Explorer XR – The development of an ocean-based immersive co-design environment

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Abstract

The NEMO project (New Economic Model for the Oceans) tackles ocean-related issues from a design perspective.

The initial NEMO project is based on an experimental data gathering using 4K cameras to capture objects along a ship voyage of 6,070 nautical miles from Kangerlussuaq (Greenland) to Poole (UK) via Sardinia (Italy). This data was combined with recorded GPS coordinates to visualize the journey using the Cesium.js environment. Several objects were identified and mapped to the corresponding locations of the ship trajectory.

In this work, we are using this initial web visualization as starting point to create a first prototype of an UNREAL engine-based immersive environment which can be explored within the new RCA SNAP Visualization Lab facility. Based on a previous co-design workshop locally ran at the RNLI headquarters in Poole, we started to explore opportunities to enable similar experiences in an immersive 3D environment. The ultimate aim is to enable collaborative data visualization and exploration in the context of co-design workshops.

In this way, we are combining Macro-Meso-Micro perspectives with the purpose to provide on one hand a holistic overview of the journey, and on the other hand enable place-based exploration of ocean- and coast-related scenarios.

Introduction

The ocean is one of the most critical places for addressing major climate induced impacts on the world's population and ecosystems covering 71% of the plant's surface [1], [2], yet only 5% of the ocean has been explored [3]. Cascading regime shifts (tipping points) remain a major future risk from the world's ocean affecting food supply, coastal erosion, flooding, transportation and biodiversity [4]. Even though 2.4bn people live within 100km of the coasts we struggle to empathize with the ocean as a place that can change our behaviors on land [5]. UNESCO's Ocean Decade seeks to improve the future of the ocean by integrating global interdisciplinary collaboration and identifying gaps in knowledge and capability [6]. Two of these involve connecting ocean science data with stakeholders and leveraging the benefits of co-design to enhance coastal community resilience.

As part of the endeavor to connect ocean science and data with coastal communities for evidence-based decision making and actions, the NEMO project team carried out an initial experimental data gathering using 4K cameras to capture objects along a ship voyage of 6,070 nautical miles from Kangerlussuaq, Greenland to Poole, UK via Sardinia, Italy in 2021 [7]. The identified objects were visualized in an interactive web-based globe showing their geographic locations and associated video footages. The visualization platform supported subsequent activities (e.g., workshops with diverse stakeholders) to identify future design opportunities.

Workshops were hosted in Poole (UK) as well as Nuuk (Greenland) to understand local communities' perception towards ocean related issues. From the workshops, we were able to learn the similarities and differences of people's connection to the ocean from different locations.

Objective

In the NEMO Explorer XR project, we investigate the new opportunities to engage stakeholders with immersive technologies. We are developing a fully immersive and interactive virtual environment, that should ultimately allow participants to visualize various data layers and to annotate data while exploring the environment. As previous workshops were hosted in the local area that participants were familiar with, this virtual environment should allow them to experience a new area or places that are out of reach.

Based on our experiences with co-design workshops in the educational as well as professional area [7], [8], [9], this environment will be a test bed to bring together co-design with an immersive lab environment. Different from previous methods of presenting and interacting with data through web-based visualization or VR headsets, we create a new interactive system situated in a Data Visualization Lab.

Here, we are discussing the NEMO Explorer XR version 0.9, which is taking advantage of the web-based NEMO Explorer 1.1.1. This is a starting point to develop a fully functional version providing similar capabilities like the web version.

Figure 1. The St Helena ship showing camera location and angles (top), installation of cameras (bottom left), control unit and NVR's (bottom centre) and camera shroud (bottom right).

Methods

Design is a highly tangible discipline that specializes in the creation of objects (and also services, systems, interactions and experiences) that can change behavior in individuals and groups. Bearing this in mind we decided to take a cross-sectional approach to design and build a sensor package that could identify several visible objects on the surface of the ocean during the voyage. We would later introduce these objects via data visualization to Greenlandic and UK coastal communities to draw out ocean relationship narratives to tackle climate change.

Data Acquisition

The sensor package was designed, built, tested and installed within a 9-week period during a Covid-19 lockdown in the UK and Greenland. We decided to take an 'industrial lego' development approach due to the short time window for installation developing two connected assemblies of off-the-shelf technologies. The control unit (Figure 1 lower center) comprising of a UniFi *Network Video Recorder (NVR)* [10] with 4x 8tb AI rated hard drives, a *Power over Ethernet* unit *(PoE)*, power conditioner, mini PC, touchscreen, cooling units and associated connectors installed into vibration insulated racks inside a Gator case for travel and operational protection. The control unit was connected to two pairs of cameras mounted inside a chassis in a custom designed protective angled shroud via 25m ethernet cables routed through the radio room wall, ship's heads and monkey island stanchion up to the monkey island upper rail approximately 30 m above and angled down to the sea (Figure 1 top and Figure 1 bottom left). The shroud was designed to reduce spray, discourage bird perching and reduce vibration through a rubber mounted chassis fixed to the shroud exterior (Figure 1 bottom right).

Camera Setup

Camera lenses were digitally set for wide angle and zoom (4mm x 12mm) and had both sound and IR capability though these would be of limited use due to height above the water (Figure 1 bottom right). The sensor package would be switched on manually then run continuously across the Atlantic 24 hours a day with a drive swap in Sardinia due to the risk of over-write as a potential result of limited capacity.

We considered streaming the data however marine data rates are low and costs were prohibitive. A Fleetmon GPS asset tracker was also installed allowing the team an autonomous tracking and recording device with access to journey visualization, speeds and locations [11]. The UniFI NVR (running UniFi Software version 4) had machine vision AI capability primarily designed for security purposes on land to identify people and vehicles [10].

The Journey

The journey took place on the RMS St. Helena ship part of the Electric off-road racing competition Extreme E. The vessel is used to transport staff, drivers and cars to different remote locations in the world where the races are taking place. The locations are chosen with the purpose to raise awareness for aspects of climate change, and Extreme E maintains a "Legacy Programme" which intends to provide social and environmental support for those locations [12], [13].

The recorded journey started from Kangerlussuaq (Greenland, 14.09.2021), went over Cagliari (Sardinia, 03.10.2023) and finished in Poole (UK, 23.11.2023) (see also Figure 4 top). Over the whole distance of 6,070 Nautical miles, the installed four cameras recorded 82 TB of video data. During the journey, GPS coordinates were recorded on average every 30 minutes. Due to unstable connectivity, the concrete time stamps are not coherent and might differ by multiple seconds difference in duration.

After swapping all four drives along with the NVR (the drives are coded to the specific NVR) and inspecting the system when the ship docked in Cagliari Sardinia, we recovered the final set of drives from Poole in the UK. The drives were connected to the UniFi cloud system and manual object identification was undertaken to compare to the AI data gathered (see also Figure 3 top).

Data Annotation

For the manual object identification, a research assistant annotated over 12,000 nautical miles of video recording using the Pomodoro slicing technique [14]: the video data was viewed for 25 min, and after a break for several minutes, the next segment was analysed for 25 min, and repeat.

One representative screenshot for each identified object was taken from the video (Figure 2 top shows example photos). Objects that were detected but difficult to recognise were discussed among the team members, and we labelled the unresolved ones as *Unknown* (under *Other* subcategory).

The following three main categories and nine subcategories were identified (Figure 2 bottom):

1. In Ocean: Fish, Megafauna, Plants;
2. On Ocean: Ships, Garbage, Other; and
3. Above Ocean: Birds, Events, Aeroplanes.

	In Ocean			On Ocean			Above Ocean			AI
	Megafauna	Plants	Fish	Ships	Garbage	Other	Birds	Aeroplanes	Events	AI Identified
Sub Totals	106	83	41	660	333	34	1833	61	454	164
Grand Total									3605	
Human total									1054	
Nature total									2476	
In Ocean									230	
On Ocean									993	
Above Ocean									2348	

Figure 2. Top: Example photos from the recorded videos of identified objects. Bottom: The three main categories and 9 subcategories used for object identification.

Data Integration

For the purpose of data annotation, Google Sheets™ was used to enable collaborative editing and curation of the data. The GPS data exported from UniFi was expanded by additional information by using scripting. GPS locations of identified events were calculated by using linear interpolation between the previous and subsequent recorded GPS location. For this purpose, Google™ AppScript was used.

Each row in the spreadsheet represented either a recorded GPS location or an identified event. The events were then connected via direct links, encoding 1) the UniFi account-related URL, 2) the recorded camera ID, and 3) the corresponding time stamp to be able to link each location to the corresponding video footage.

Moreover, the previously mentioned representative screenshots taken during the data annotation process (using the Pomodoro slicing technique) were linked.

Using AppScript, this information was parsed to a KML file which was then used in Cesium to visualize the journey on an explorable 3D map and enable the direct linkage to the corresponding video data (see also screenshots on Figure 2 top).

Figure 3 shows the general system architecture as used for the NEMO Explorer 1.1.1: as previously mentioned, the video data recorded on the ship (Figure 3 top right) was transferred to storage of the NVR servers at the RCA (Figure 3 top left).

Then, the CesiumJS framework was used to enable to explore the journey (as seen in Figure 4) [15]. Cesium connects to external map providers such as Bing Maps™ or Google Maps™, to visualize the data. These map providers use external servers (Figure 3 right bottom) which CesiumJS (Figure 3 left bottom) is connecting to in order to fetch the data.

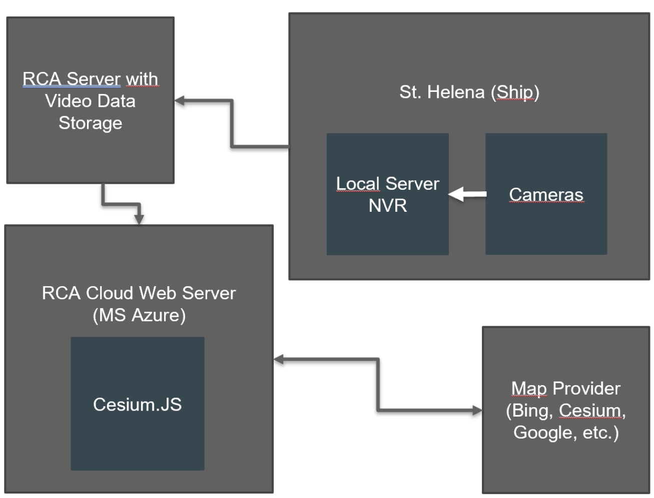

Figure 3. NEMO Explorer 1.1.1 System Architecture.

Data Exploration

Here, we are exploring two use cases of the new system, making use of the innovative functionality combining map-based visualization at the macro scale, enabling exploration at the meso-scale, and diving into the current situation at the micro-scale.

The first use case is shortly discussing the web-based NEMO Explorer 1.1.1, whereas the second one is discussing the NEMO Explorer XR 0.9.

Web-based Exploration of Ocean Objects

The initial purpose of the system illustrated in Figure 3 is the web-based exploration of the St. Helena journey providing access to the map as well as the location-based video data. In this way, expert users can explore the data on multiple levels.

Following the well-established information seeking mantra – Overview First, Zoom and Filter, Details On Demand – the journey can be explored on multiple levels [16].

One of the main data layers includes bird sightings. The annotated journey enables ornithologists to identify points of interest on the macro level, depending on the time and location they are interested in. The system provides users an initial preview of the scenario (screenshot as seen in Figure 2 top) including detailed information like time and annotations. Then, the user can navigate to the corresponding timestamp in the video data and explore the bird movement in detail, at the micro level.

The NEMO Explorer 1.1.1 is optimized for single users and comes with the big advantage of being web-based, and in this way can be used with a browser on regular computers. The current system is not optimized for mobile phone usage: As the displays of mobile phones are usually very tiny, the optimization for mobile devices has a lower priority for this project – especially as the inspection of video data on a tiny screen is of very limited usage.

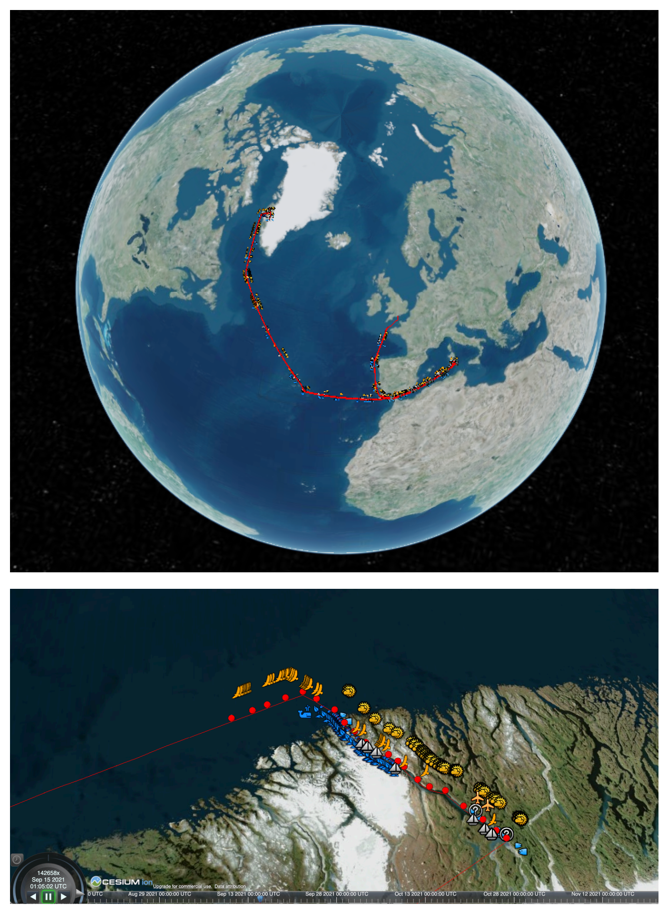

Figure 4. NEMO Explorer 1.1.1: Top: Overview of the St. Helena journey from Kangerlussuaq (Greenland) to Poole (UK) via Sardinia (Italy) based on object's GPS data locations. Bottom: Navigated to the initial part of the journey at Greenland, the different icons show the different object categories as discussed in Figure 2 bottom.

XR based Exploration of Ocean Objects

As can be seen in Figure 1 top, a special feature of the setup discussed here is that video cameras are located at both sides of the ship – port (left) and starboard (right). Although this setup does not enable a full 360 degree view, the cameras are covering a large area at each side of the ship. Going back to the previous examples of the Ornithologists: In this way, our setup enables observers to follow animal sightings from one side of the boat to the other one.

The initial test setup of the NEMO Explorer XR 0.9 is based on the idea to take advantage of the camera setup and to enable users to explore the data 1) on a large scale and, 2) with multiple users – enabling co-exploration and co-design workshops.

For this purpose, we were using the newly established (2024) *Royal College of Art SNAP Visualization Lab (Vis Lab)* which is equipped with five BARCO™ 4K projectors, each one connected to a node computer including each an NVIDIA RTX A6000: one large front projection (consisting of three vertically oriented projectors) and two side projections, including active *Stereoscopic 3D (S3D)* projection capabilities. A central host computer with the same basic hardware configuration as the five node computers synchronizes the rendering and network communication.

The general idea of this project is to create an interactive XR system which integrates UNREAL Engine 5 with our existing web-based Cesium visualization platform, the previously discussed NEMO Explorer. In particular this approach is supported by the Cesium for UNREAL plugin [17].

Figure 5 shows the use of UNREAL for Cesium, using the center, left and right projection area to explore the virtual Cesium maps.

Figure 5. Using UNREAL Engine in combination with Cesium in the RCA SNAP VisLab – projecting the 3D map at the left, center and right screen.

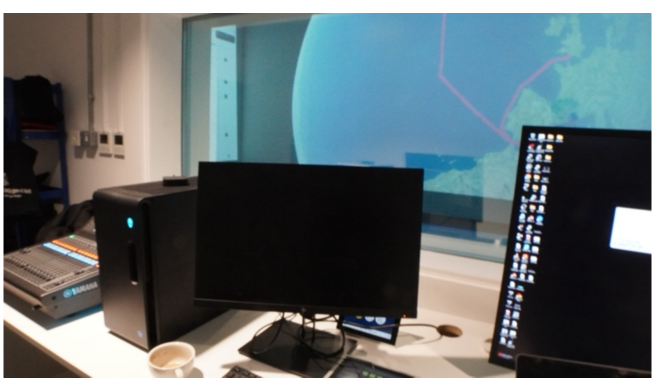

Figure 6. Setup in the RCA SNAP Vis Lab with the NEMO XR PC.

Figure 7. Exploring the St. Helena journey, starting from Kangerlussuaq in Greenland. The center shows the UNREAL Engine 5.1 visualization using the Cesium UNREAL implementation. Left (port) and right (starboard) the recorded videos in this area are shown, using the UniFi environment to show the data. Top photo: a person exploring video recordings at ship's port-side.

The web-based Cesium platform provides the basemaps and the reference system to map our data to the correct location, whereas the UNREAL engine provides additional functionality for enhanced rendering of the highly detailed local environment in 3D.

Figure 6 shows the initial setup: the NEMO XR computer – a comprehensive Windows 11 computer equipped with an NVIDIA GeForce RTX 4090 is connected to the server computer which streams the video data with 4K resolution output to the front projection. In this way, the virtual map exploration using the NEMO Explorer XR 0.9 is streamed on large scale to the front screen.

To stream the video data, the two node computers connected to the left and right projectors run the NEMO Explorer 1.1.1 which is connecting to the UniFi system to stream the corresponding video data – for the port and starboard side on the respective projectors. An example can be seen in Figure 7:

Figure 7 top shows the starting point of the journey which roughly corresponds to the rightmost GPS coordinate seen on the map in Figure 4 bottom. Starting from there, the journey moves forward along the GPS coordinates, approaching the Southwest coast of Greenland (Figure 7 bottom) before entering the Labrador Sea.

Discussion & Outlook

We presented here a short introduction of the web-based NEMO Explorer 1.1.1 as a fully operation system, as well as the NEMO Explorer XR 0.9 prototype with some basic functionality running in the novel RCA Vis Lab.

Our current web-based system provides already the interactive exploration at the macro-, meso-, and micro-scale. The global journey can be explored, patterns of identified objects – such as clusters – can be inspected, and the user can explore the local situation by accessing the data and navigating to the corresponding time point in the video.

The NEMO Explorer XR is intended to support two-way communication: while the participants explore the virtual environment, they can share their thoughts or feedback by annotating directly on the visuals in a co-design workshop. We will collect the annotation as part of the output generated from workshops in a new format.

The prototype of the XR version presented here provides already initial exploration and visualization of the GPS data which was imported into Cesium for UNREAL and in the way the macro scale is implemented. Until now, the object categorization was not transferred to the system, this will be one of the next steps. This will then also enable the identification of patterns at the mesoscale.

Moreover, we emulated here the microscale information by showing the corresponding recorded videos at both sides of the Vis Lab, whereas in the center the map was shown. This information is not automatically synchronized as of now.

The optimization of this system will be done based on our previous work, including the immersive exploration of bird trajectories [18], [19], and will probably implement elements of our previously developed Stereoscopic Space Map approach [20].

After the development stage, we will invite participants to the Vis Lab to run a co-design workshop in this new environment. Feedback will be collected on areas for future improvement.

In addition to the identified objects and video footage we have collected and discussed here, we are planning to integrate various types of other datasets to help build the context of locations we are interested in, e.g., 3D city or landscape models, demographic data, environmental data, etc. In addition, we are planning to make use of the extensive visualization capabilities of UNREAL Engine 5 [21].

Abbreviations

- 2D two-dimensional
- 3D three-dimensional
- AR Augmented Reality
- HMD Head-Mounted Display
- MR Mixed Reality
- VR Virtual Reality
- XR Extended Reality (including VR, AR, MR)

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