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Short Paper

Design Considerations for Immersive Analytics of Bird Movements Obtained by Miniaturised GPS Sensors

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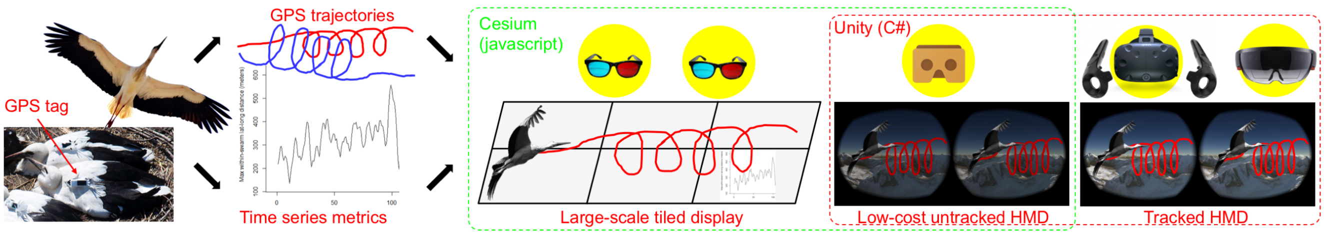

Figure 1: *One dataset, multiple immersive environments. A typical setup of a sensor for movement and other (e. g. temperature) data acquisition attached to a bird. The data is transferred via the GSM (mobile phone) network, and then visualised in different immersive environments to facilitate an unbiased comparison.*

Abstract

Recent advances in miniaturising sensor tags allow to obtain high-resolution bird trajectories, presenting an opportunity for immersive close-up observation of individual and group behaviour in mid-air. The combination of geographical, environmental, and movement data is well suited for investigation in immersive analytics environments. We explore the benefits and requirements of a wide range of such environments, and illustrate a multi-platform immersive analytics solution, based on a tiled 3D display wall and head-mounted displays (Google Cardboard, HTC Vive and Microsoft Hololens). Tailored to biologists studying bird movement data, the immersive environment provides a novel interactive mode to explore the geolocational time-series data. This paper aims to inform the 3D visualisation research community about design considerations obtained from a real world data set in different 3D immersive environments. This work also contributes to ongoing research efforts to promote better understanding of bird migration and the associated environmental factors at the planet-level scale, thereby capturing the public awareness of environmental issues.

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications—Immersive Analytics in Ornithology

1. Introduction

Advances in display technologies and visualisation platforms provide several options for interactive and immersive visual representations. However, the requirements for presentation and Immersive Analytics (IA), as well as the advantages and disadvantages of the recent VR (Virtual Reality) and AR (Augmented Reality) platforms are not well investigated yet, creating a gap for visualisation designers and researchers alike. This paper presents a practical overview and comparison of potential platforms and an initial study, aiming towards filling the gap in the 3D visualisation research community through a real world case study with implementations on different 3D immersive environments. We investigate the requirements and challenges of visualising movement data of large migratory bird

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species for presentation and analysis, and discuss the characteristics, benefits, and shortcomings of available technologies in the context of the implemented prototypes.

Display technologies such as CAVEs [CNSD*92], PowerWalls [EBG*92] and head-mounted displays (HMDs, such as HTC Vive and Google Cardboard) [Sut68] showed significant improvements in the last decade, e.g. regarding resolution and tracking capabilities. They have advantages (screen area, resolution) over traditional single panel displays especially when viewing dense information such as GPS trajectory data. Immersive 3D technologies, being increasingly affordable, are appealing platforms for both visualisation applications and public outreach. The young field of Immersive Analytics (IA) aims to develop methodologies for collaboration, interaction, visualisation, and analytics to support reasoning and decision-making in immersive environments [CCC*15]. These technologies have had some success in promoting public awareness in other fields, such as biomedicine, archaeology and ecology (e. g. [CLDL*16, SBB*17]), and were applied in a few prototype implementations (e. g. [SSPOJ16]), but applications in biology are still comparatively sparse. Rather, current IA research is focused on fundamental questions using abstract tasks [CDK*17].

While there are already solid foundations for visual analytics of movement data [AAB*13], visualising bird movements has only recently become a cross-disciplinary research opportunity for biologists and computer scientists [KCJW15]. Visualisation of 3D movement data can help scientists work towards making significant advances in animal movement research [SBvLP*12]. Cheap, lightweight, high-resolution tracking technology now provides the data, analytic challenges and questions to be handled and approached using immersive 3D visualisation technologies. Interactive visualisation of movement data and interactions between free-living animals have hardly been studied. At this new research frontier, we aim to perform a benchmark study by employing a real-world data set in multiple immersive environments (see Fig. 1), with two main goals: (1) inform the 3D visualisation community on design considerations and (2) create prototype visualisation tools for biologists, forming the basis for further immersive analytics applications. Making use of a unique tracking data set of a group of flying white storks, we provide biologists with the opportunity to explore different tools that allow them – to various degrees – to 'fly with' and learn from their animals. For this purpose, we present here initial results from our ongoing research project and explore this new application area.

2. Visual Encoding, User Requirements and Use Cases

In 3D immersive environments, we can present four dimensions of space and time via 3D visualisation and dynamic animation, and encode additional dimensions by integrating standard data visualisation techniques [WGK10], e. g. by mapping data on visual cues such as colour. Text labels allow to show additional details next to the objects (bird, terrain). Interactivity also allows expert users to show or hide visual elements to produce a custom data view.

Within this project we collaborate with researchers from biology in order to understand their requirements for analyses and use-cases. In an informal expert review we collected information on research questions, data availability, current analytical tools and workflows used by them. We identified three main use cases: 1) exploratory analysis, 2) hypothesis testing, and 3) outreach for presenting the collected data to decision makers and the general public.

	Variable	Description
(green)	**Time**	Time stamp of sensor measurements
(green)	**Bird ID**	ID of the tracked bird / sensor
(green)	**Lat**	Measured latitude
(green)	**Long**	Measured longitude
(green)	**Alt**	Measured altitude
(green)	**Heading**	Intended movement direction
(red)	**Direction**	Actual movement direction
(red)	**Wind**	Wind velocity estimates [WBK*16]
(red)	**Distances**	Distances between birds
(blue)	**Terrain, Vegetation, Visual field, Auditory field**	

Table 1: *Bird trajectory data used in this study. Primary (measured) data is indicated with green colour, secondary (derived) with red, additional influence factors used in the analysis with blue.*

Biologists explore measured bird behaviour data, together with influence factors that might be important to bird decision making and collective behaviour, to infer the mechanisms behind this decision making and communication in groups. In the specific example of the white stork tracking study, we determined that the data is usually a combination of movement GPS and environmental data (e. g. wind) [FFB*16]. Influence factors include terrain, vegetation, weather, distance travelled, individual physiological properties, and health. Although atmospheric conditions are a crucial factor influencing bird movements, these data are sparse and hard to measure. Thus, deriving wind conditions from the birds' movements is important, and good visualisation techniques may assist on that. Weather data could provide regional temperature and wind conditions, but would be too imprecise to locate local thermal spots or changing conditions in different altitudes [vWKK*12]. In addition, even the sensor data is incomplete, e. g. GPS information is only available for short time bursts.

Allowing researchers to put themselves in the position of the bird provides opportunities to understand the decision-making process of the bird flock, or the intricate differences between individual flock members while moving on small and large spatial scales.

3. Materials and Methods

3.1. Data used in this study

The data used in this study was collected using miniaturised GPS sensors (see Fig. 1) as described in [WBK*16], and will be made freely available at Movebank [MB]. The GPS data consists of geographic position and elevation in World Geodetic System (WGS84) coordinates, speed and heading (see Tab. 1). Raw data was obtained in Keyhole Markup Language (KML), an international standard of the Open Geospatial Consortium, compatible to multiple geographical visualisation platforms.

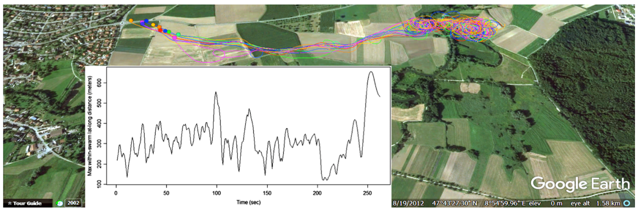

Figure 2: *Visualisation of the bird trajectories in Google Earth.*

3.2. 3D visualisation on a tiled display wall

To visualise geographical data on large-scale tiled displays without sacrificing resolution, we first utilised the Google Earth platform (see Fig. 2) using the KML bird trajectories as input data, and extending a Google Earth implementation based on previous studies [NWZ*16]. Different geographical layers are overlaid on top of the satellite imagery, and individual layers can be toggled or blended. Based on the KML data, inter-bird distances were computed and plotted using the R language [R D08], together with the *moveWindSpeed* library to estimate the ground wind speed [WBK*16]. Overlaid KML data are dynamic, and can be animated using time-series sliders. Fig. 2 displays a Google Earth trajectory visualisation of a flock of 11 birds together with the inter-bird distance plot. Google Earth supports large-scale high-resolution displays, but this proprietary platform also limits the capabilities to manipulate visualisation features. Neither Google Maps nor Google Earth can visualise KML data in combination with Stereoscopic 3D (S3D) rendering, an important requirement for immersive analysis [Goo16, SBB*17]. Therefore, they are excluded from the following analyses.

3.3. S3D visualisation on a tiled 3D display wall

For the aforementioned reasons, the display wall visualisation approach was extended into the third dimension by using the open-source, cross-platform Cesium geographical visualisation library [ces17]. It supports tiled displays, the KML format, as well as stereoscopic rendering in WebVR and the HTML5 standard (Fig. 3) [web17]. In this implementation, the stereoscopic effect was optimised for approximately 1 meter viewing distance. In addition, the visualisation was distributed over different monitors, enabling the visualisation of individual bird behaviour side-by-side – in our case six monitors could show six different perspectives of one or many birds, or first-person perspectives of six different birds.

3.4. Low-cost untracked mobile VR visualisation

The Cesium-based semi-immersive visualisation of bird trajectories on the tiled 3D display wall presents a community-viewing environment. With the maturity of virtual reality headsets (HTC Vive, Google Cardboard), it is a natural development to extend this semi-immersive to a fully immersive environment, allowing users a 360-degree experience. The original VR implementation of Cesium is optimised for the use with current mobile phones, therefore Cesium was also used for the Google Cardboard-based approach.

Figure 3: *Stereoscopic visualisation of the bird trajectories using Cesium VR as a server and a tiled 3D display wall with polarised glasses as a display client.*

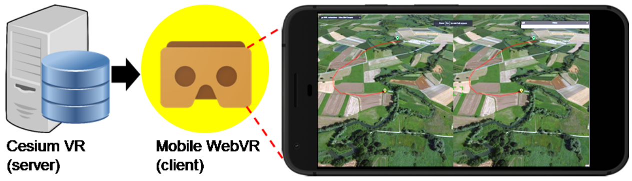

Figure 4: *Stereoscopic visualisation of the bird trajectories using Cesium VR as implemented on the Chrome mobile browser.*

The Cesium rendering client for the mobile phone is a WebVR-compatible browser (Chrome Experimental Browser or Firefox Nightly Builds), connecting to a server via IP address (Fig. 4 left).

The Google Cardboard paired with an Android device only allows viewing of simple 3D objects due to its relative slow processor (see Fig. 4 for this setup). Without additional technologies, position tracking is not possible in this environment. Therefore, only the head movement can be translated to perspectival changes. The large advantage is the mobile usage of this technology, with cheap devices available to most users, disadvantages are low visual quality, low immersion, and restricted interaction.

3.5. Tracked VR visualisation

Overcoming the resolution and latency issues of the Google Cardboard, the HTC Vive headset allows viewers to see a complex scene in high resolution. The virtual reality application for HTC Vive was implemented in the Unity 5.5 platform, utilising the Steam VR SDK. KML input files were parsed and then transformed into a spline curve using the Bezier spline library in Unity. The real-world GPS data (latitude, longitude, height) was converted to meters using the haversine formula [Sin84] and then rescaled at 1:100 ratio based on the room parameters (4x4 m^2) to preserve the fidelity of the trajectories. Simple room-scale models of a flock of birds were created based on the same KML trajectory data set in the Unity 3D platform, providing head location, and movement tracking. User interaction is achieved via two hand-driven HTC Vive controllers with haptic feedback to accommodate natural human senses (see Fig. 5). Users can walk around the virtual environment using the room-scale optical tracker, and a teleport function allows rapid navigation in the simulated world. The floor background was overlaid

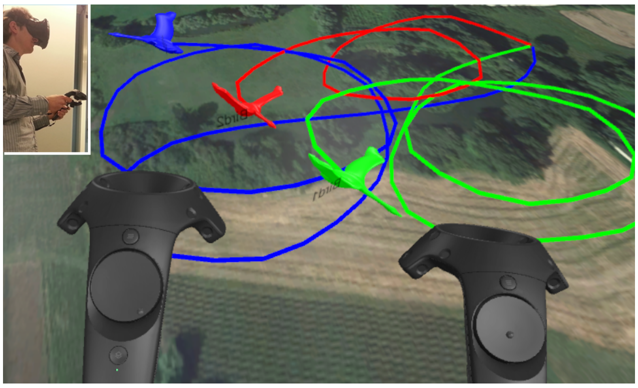

Figure 5: *Tracked HMD visualisation of the bird trajectories in an immersive environment. Using the HTC Vive and its controllers, users can interact with the bird trajectories.*

with satellite terrain imagery and scaled to room parameters, and the flying birds were modelled and animated with Blender.

3.6. Tracked AR visualisation

To tackle the spatial tethering constraint of the HTC Vive headset, we further implemented bird trajectories visualisation on the Microsoft Hololens mixed reality platform. By using a transparent display, the Hololens enables viewers to see a complex scene combining both virtual object and the real world environment, while allowing the users to similarly walk between the bird trajectories to investigate the data using hand gesture. The implemented software environment is based on the previously-mentioned flock of birds visualisation used for the HTC Vive. Using a VR headset in fieldwork has been hindered by the lack of lightweight, untethered HMDs. The emerging class of untethered tracked AR headset such as the Hololens presents a promising step towards making fieldwork VR feasible, but is still hampered by the low outdoor contrast and the requirement of stable internet connection.

3.7. Comparison and design considerations

From the 3D visualisation developer's perspective, we summarised the experience in constructing the bird movement visualisation, which can be also informative for visualising other types of 3D data. Design considerations for 3D immersive visualisation hardware are shown in Table 2, where the different hardware is broadly categorised as S3D Tiled Display (tiled 3D display wall), Tracked VR (Vive), Mobile/Untracked VR (Cardboard), and Tracked AR (Hololens). In addition, design considerations for software development platforms are summarised in Table 3, where three main platforms (Google Earth, Cesium, Unity) are contrasted. While all platforms are VR-ready, Google Earth VR is currently not IA-ready, as it does not support the inclusion of further external data.

4. Discussion and Expert Evaluation

In order to evaluate the potential of the different devices discussed here and to put them in context, an initial expert study with three

	S3D Tiled Display	**Tracked VR**	**Mobile VR**	**Tracked AR**
Example device	S3DWall	Vive	Cardboard	Hololens
Ease of setup	-	+	++	+
Haptic feedback	- -	++	+	- -
Field of view	+	++	+	-
S3D quality	+	++	o	+
Visual quality	++	++	+	o
Ease of interact.	++	++	+	o
Immers. qual.	+	++	+	+
Cost effect.	-	++	++	o
Regular use	++	+	+	o
Short term (<1h)	++	++	++	++
Long term (>1h)	++	-	-	-
Colla. potential	++	++	-	+

Table 2: *Hardware design consideration, developer's perspective (top) and expert user's perspective (gray background)*

	Google Earth	**Cesium**	**Unity**
Visual quality	D+/V++	o	+
Ease of expansion	- -	o	++
Platform maturity	+	-	++
Custom data?	D✓,V✗	✓	✓
Installation?	D,V✗, W✓	✗	D✓,W✗
Open Source?	✗	✓	✗/✓

Table 3: *Software design consideration, from developer's perspective. Abbreviations: (D)esktop, (V)R release, (W)eb.*

subjects was conducted, using each of the previously discussed technologies except the standard 2D Google Earth approach, as the focus in this study was laid on new immersive analysis methods. The guided discussion was accompanied by a questionnaire, evaluating the properties shown in Tab. 2 bottom. The corresponding table section summarises the feedback of the expert users, estimating their expectations towards the different hardware setups.

The expert feedback provided valuable comments and assessment supporting the future development of new VR/IA platforms for 3D bird movement. The fully-immersive HMDs were the best technology in terms of immersion and visual quality. But all HMDs, as well as the Hololens and Cardboard, are problematic in that the subjects did not expect to use them for longer periods (>1h) as required for specific tasks. In addition, Vive and Hololens are spatially tethered and in case of the Vive confined to a room-based indoor environment. In terms of viewer's comfort, the Hololens was found to be superior to the Google Cardboard, but can be inferior to the HTC Vive. The tiled 3D display wall cannot provide full immersion, but the visual quality is among the best, allowing long term use. However, the downside is its substantial cost.

Also, the expected visual quality of the bird visualisation strongly depends on the application case: the icon-based visualisation known from Google Earth and Cesium are sufficient for a global flock analysis (Fig. 2). A bounding box-like visualisation is appropriate in case the bird's orientation is irrelevant or uncertain. More complex and animated visualisations are only relevant in case the required data is available or predictable with high certainty (Fig. 5). A fully textured photo-realistic bird model is usually not required unless for outreach. However, animation including bird flapping wings and trajectory trail rendering are specifically helpful to domain experts to study bird motions and flock behaviours.

In terms of collaborative work the participants concluded that the tiled 3D display wall is very promising. More diverse was their opinion for the other technologies, as for VR the real world as well as the collaborators are not (fully) visible and for the recent AR technologies the visual field is quite narrow. Whereas the visual quality of the Cardboard approach is worst – basically depending on the quality of the used mobile device – it has the highest potential for daily in-field use, e. g. when observing and tracking a flock of birds in nature. In terms of motion sickness, which is a typical problem of VR environments such as the Vive, the Hololens has the big advantage to show the real world in the background, widely preventing users from getting motion sick.

5. Outlook

Engaging researchers in a visually immersive environment while providing direct access to their data, with representations of crucial influence factors on bird behaviour, is a key advantage of the discussed IA environments. There is a high potential for developing a collaborative platform for bird behaviour analytics, for which we proposed and compared different strategies. In the future, these approaches could be extended to provide highly realistic bird models, simulations, automatic terrain generation and weather integration, or be adjusted to meet the requirements of public exhibitions. One key finding is that design and implementation depend on the needs of domain experts, together with the practical constraints (such as field work conditions, computational power and network speed).

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