An Analytics System for the Evaluation of Interactions of Museum Visitors in Augmented Reality Tours

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ABSTRACT

This paper presents the design, implementation, and evaluation of a system that supports the analysis of visitor interactions with augmented reality (AR) content in museum exhibitions. It can be used in conjunction with the AR authoring and presentation system InfoGrid. InfoGrid enables museum professionals to setup indoor and outdoor AR tours by connecting visual features of physical exhibits with different kinds of media. Visitors can retrieve these media by using the InfoGrid mobile app and scanning the target areas. The analytics application presented in this paper aims to help museum professionals to get an understanding of how visitors are using the AR tours they created. It shows how visitors interact with each AR element and reveals if some elements have been unrecognized. It allows museum professionals to visually inspect the data mapped onto a digital floor plan of the museum. The system visualizes movement paths on the floor plan as well as heatmaps that represent the overall time spent in an exhibit. Data for the evaluation system is anonymously generated by using a logging mechanism of the InfoGrid AR mobile app. Finally, we present a usability evaluation of the analytics system, discuss the results as well as future work.

CCS CONCEPTS

•Human-centered computing ~ Ubiquitous and mobile computing ~ Ubiquitous and mobile computing systems and tools •Human-centered computing ~ Human computer interaction (HCI) ~ Interaction paradigms ~ Mixed / augmented reality

KEYWORDS

Visitor Evaluation, Augmented Reality, Museum Exhibition, Cultural Heritage

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1 Introduction

Museums are faced with the challenge of attracting and retaining audiences. One direction to offer a rich visitor experience is by introducing learning applications that adapt to the visitors in terms of language and content. Furthermore, applications can be created in a way that provides seamless access to the digital content of the museums through different interconnected display devices such as multi-touch walls and tables, tangible media, and mobile devices. Having these devices interoperating on one software platform opens the possibility to fully use the presentation advantage of each specific device while telling a coherent narrative. In our research project *Ambient Learning Spaces (ALS)* we are working on the development of such an interconnected learning platform that can be used in schools and museums [1][2]. One of the frontend applications we created for the mobile context is the AR authoring and presentation system *InfoGrid* [3][4]. With InfoGrid museum professionals can create AR tours of their exhibitions themselves without any programming or other technical knowledge.

These AR tours consist of multiple image targets connected to different kinds of media such as images, videos, audio files, animated 3D objects, and so-called Asset Collections. Asset Collections are an overlay format we defined, to be able to develop AR scenes dynamically outside of the AR app itself. Once a scene is created, it can be imported dynamically at runtime without the need to change the InfoGrid mobile application itself. In this context, we also experimented to provide user-adapted narrative tours, which is also an active area of research [5]. Once the museum professional finished setting up a new or changed AR tour, it is still unclear how visitors perceive and interact with the media of the tour. However, understanding visitor needs and interests and aiming to satisfy them is at the heart of the economic and cultural goals of museums [6]. Other researchers suggested using studies to understand visitor experiences [7]. Visitor studies are time-consuming and only reflect information gathered during the period of the study. Using digital logging and analysis tools user studies can be performed continuously in a fully automated process. This also minimizes the effort for the visitors as no extra questionnaires are needed.

Meanwhile, it is standard practice to use anonymous log files to understand how systems or web sites are perceived by their users. However, in most physical spaces, like museums, these tools are not available. When museums start to offer digital content through mobile apps, it becomes possible to investigate the anonymous data collected to better understand how the physical exhibition is perceived by visitors. When logging interaction data using InfoGrid, no separate tracking device is necessary. We noticed that after the setup of an AR tour with InfoGrid, museum professionals find it interesting to see whether users found and perceived all of the prepared AR elements and how long they interacted with them. To make this data practical and understandable, we developed a graphical evaluation system for user interactions with AR elements. The evaluation system additionally provides interfaces for applications running on the same platform on other display devices inside the museum. By this, the logging and analysis process becomes integrated through all interactive devices in the museum.

2 Related Work

Publications on AR in the area of cultural and natural heritage is an intensively researched field [8][9][10][11][12]. Bekele et al. present a survey on current augmented, virtual, and mixed reality publications in cultural heritage (CH) [13].

Another field of research is about learning motivation. Vargas et al. present a survey on the learning motivation in CH context using AR. They conclude that using AR for CH education generates a positive impact on motivation for topics related to art, history, sciences, etc. [14]. Another area of research focuses on user acceptance of information and communication technologies (ICT). Owen et al. describe a study on visitors' evaluation of technology used at cultural heritage sites. They analyze the unique capabilities of ICT in CH context. Part of their work also deals with AR technologies [15]. In the area of evaluation of web sites, a lot of professional open-source tools like Grafana and commercial tools like Google Analytics exist, that help web site owners to see which navigation path the visitor followed on the webpage. It also helps to find out how much time visitors spent on individual webpages.

Only little research and a few tools can be found in the area of the evaluation of visitors' behavior using localization and image marker recognition methods. Lanir et al. used RFID and wireless sensor networks where each visitor got a little carry-on sensor. After walking through the exhibition the system displays the visitor's paths on the floor plan of the museum and saves the time spent at each point inside the museum [16]. Strohmayer et al. also used RFID technology for tracking visitors' interactions. They use visitor paths on a floor plan and heat maps of the museum to indicate where visitors have been [17]. However, few publications yet exist that describe the design and implementation of a system that visualizes interaction with AR content in the museum context.

3 Methods

In this section, we present the results of an online survey and interview results with museum professionals about the topic of evaluation visitor behavior with AR tours in museums. Furthermore, we describe the AR app InfoGrid as well as the connected backend and middleware system *NEMO (Network Environment for Multimedia Objects).*

3.1 Online Survey and Interviews

To get a better understanding of how museums evaluate their exhibitions we conducted an online survey, which was answered by 92 museum professionals of institutions throughout Germany. The survey contained questions regarding AR in general and questions regarding visitor evaluations. Furthermore, we interviewed three directors of different museums for more details. The online survey and the interview contained questions on three topics:

1. roles of the participants inside the museums and their experience with technical systems;
2. current methods of evaluating visits;
3. information they would like to get through an evaluation system.

The results show that most museums use a Point of Sale (POS) system. This system counts the number of visitors per day. Sometimes museum employees ask the visitors for the ZIP code of their home city. This ZIP code is sometimes manually recorded on paper or entered into the POS system. Additionally, in some museums, it is possible to see the age ranges of visitors due to the different pricing of admission tickets. The results also indicate that museums often offer a physical guestbook. Inside this book, visitors usually note positive or negative critics regarding the museum, the exhibits, or the personnel. It can be concluded that very little information about the visitors themselves and no data regarding the visitors' times spent at the exhibits is available. In rare cases, direct conversations with visitors or feedback from guestbooks help to improve the exhibitions. Another important fact is that the frequency of manual evaluations in museums is very low. The results of the interviews show that evaluations with larger numbers of visitors are performed occasionally or never. From these results, we conclude that an evaluation system has to be easy to use and understand and that the information collected needs to be aggregated and presented in a way so that it can easily be mapped onto the exhibition.

3.2 ALS System architecture

The system architecture of our ALS system and its learning applications consists of three main layers (Fig. 1). The first layer includes the data input and AR tour construction systems, which can be used by the museum professionals. The second or middle layer is the cloud-based semantically modeled repository called Network Environment for Multimedia Objects (NEMO). It stores the media objects as well as their higher-level descriptions and structures, the log data. It additionally contains services for media generation, annotation, and conversion. The third layer consists of the frontend applications, which are used by the museum visitors.

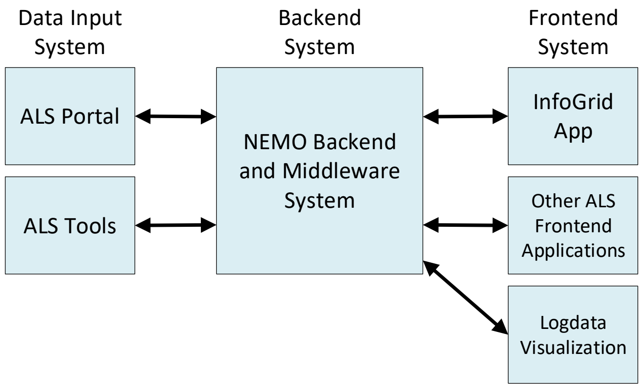

Figure 1: ALS System Architecture

To add and remove media the web-based ALS Portal can be used. All data uploaded through the ALS Portal is stored inside the NEMO instance. The ALS tools can be used to edit media and create new media from existing sources, such as videos and 3D objects. Media objects created with the ALS tools are automatically stored inside NEMO and can also be accessed through the ALS Portal and ALS frontend applications. NEMO, the ALS Portal, and parts of the ALS authoring tools have been implemented with the web development platform Microsoft ASP.NET[1] and the Windows Communication Foundation (WCF)[2].

3.3 AR App InfoGrid

InfoGrid is the frontend application that visitors can download onto their Android or iOS mobile devices to experience the AR content previously prepared by the museum professional.

The app has been developed with Unity and the Vuforia image recognition framework. The app download size is currently about 26 MB. InfoGrid downloads[3] 3D objects and Asset Collections for the selected tours at runtime in most cases from a local NEMO instance. This keeps the file size of the store download small and assures that the users will use the most recent version of the tour. Upon start, InfoGrid connects to NEMO and downloads a list of available tours. Once the user selects a tour, all 3D objects and Asset Collections are transferred to the mobile device. The app then receives the list of all augmentations for the tour. This list is internally parsed and each target augmentation is dynamically instantiated with predefined parameters. These parameters include the type of media, the file location, and additionally the translation, scaling, and rotation values. When the preparation is complete, the museum visitor can view an optional intro regarding the AR tour. When the mobile device is pointing to one of the prepared image targets, the InfoGrid app displays the instance of the augmentation on the mobile device. In the case of audio and video augmentations, the app streams the audio and video data from the connected NEMO instance. When the target is out of camera focus or terminated manually the app hides the augmentation and anonymously sends the name of the augmentation and the duration of the interaction to the NEMO backend as a logging mechanism.

3.4 Visualization System

This section is divided into three parts. The first part explains the setup of the system. The second part describes the creation of log entries through the InfoGrid app. In the third part, we present the visualization interface.

3.4.1 Setup of the System. To use the system, first of all, an AR tour has to be created. When the AR tour is available, museum professionals can set up the visualization system inside the ALS Portal by assigning a floor plan. Furthermore, the system requires the manual positioning of markers representing the elements of the AR tour onto the floor plan. These icons have to be placed on the map to the corresponding locations in the physical space. After the placement of the icons, the setup is complete.

3.4.2 Creation of Log Data through the InfoGrid App. As soon as the InfoGrid mobile app is started, it creates an anonymous random ID, which will be added to each log entry. This ID will remain the same until the app is uninstalled from the device.


```
"index": 49,
"date": "13.09.2019",
"time": "14:33:10",
"marker": "geschiebe",
"device": "HUAWEI ALE-L21",
"action": "VideoEnded",
"batterylevel": 43.0,
"network": "ReachableViaLocalAreaNetwork",
"institution": "Museum für Natur und Umwelt ",
"tourname": "Steine erzählen",
"language": "DE",
"id": "ca73a49a5420ac9e6a2181d81ca2f1c9",
"consume_time": "00:00:07:681"
```


Figure 2: JSON object that represents a sample payload of the data sent to NEMO during a log event.

Storing the IDs allows the system to filter out the IDs of developers and museum personnel to prevent them from mixing with the data of the real visitors. It will be possible to track users throughout museum institutions and several visits, which supports methods for personalization and advanced storytelling. To add IDs to the filter, the system contains a file to which all IDs that shall be filtered out can be added. When InfoGrid recognizes an AR element during use, it sends a log event to NEMO indicating which element has been found (Figure 2). When the recognition of the AR element is lost, another event will be sent to NEMO. Looking at the time difference between both events, it is possible to derive how long the user has been interacting with the AR element. The app also sends events when a tour is started or finished. Furthermore, InfoGrid sends error notifications to

[1] https://docs.microsoft.com/de-de/aspnet/core/?view=aspnetcore-3.1
[2] https://docs.microsoft.com/de-de/dotnet/framework/wcf/whats-wcf

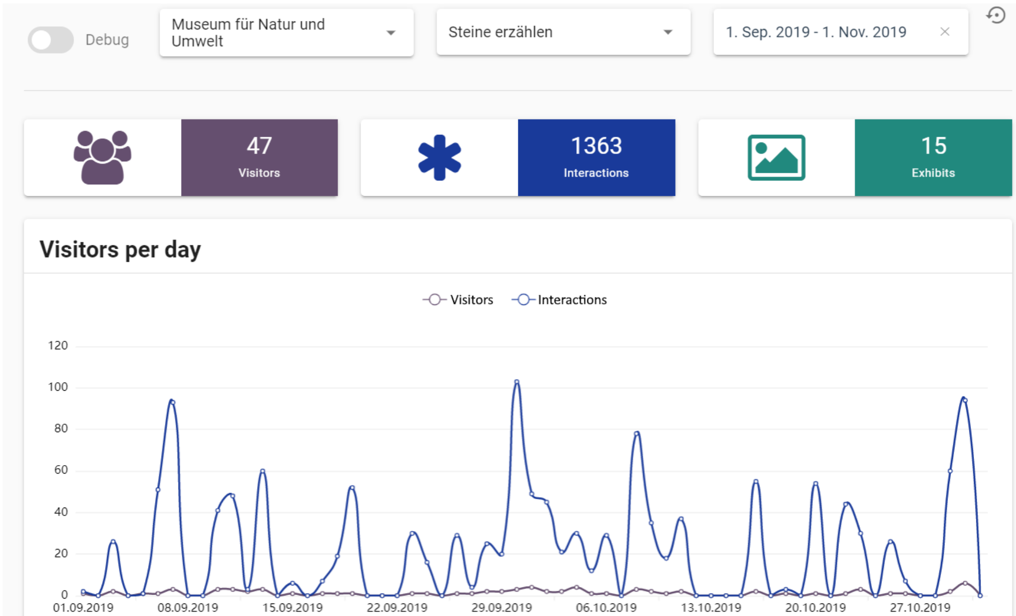

Figure 3: Visualization interface showing the number of visitors and AR interactions in a line plot.

NEMO if a media file is unavailable or some error occurred instantiating the AR element. All events are sent through secured https connections.

3.4.3 Visualization Interface. The visualization system has been implemented with the vue.js framework[4]. Museum professionals can access it through the ALS Portal. The system supports the setup of multiple AR tours, each with its floor plan. Users can analyze all tours assigned to their institution by selecting it from a dropdown menu (see Fig. 3 top left). A date range selector allows selecting specific time frames (see Fig. 4). The initial page of the visualization system shows the number of users, who used the app along with the amount of the performed interactions in a line graph as shown in Figure 3. The lines representing the visitors or interactions can be hidden and the graph automatically rescales. To get an understanding of how visitors moved through the exhibition users can switch to the map view. This view shows the floor plan along with visitor paths. Depending on the number of visitors, who used this path, it will be displayed with a thicker line. By pointing the mouse onto one of the AR elements on the map, a hint window shows how many actions were performed with the object and the total time of the interaction with the element. In case a museum professional selects only one single anonymous visitor, the system shows the direct walking path of this visitor through the exhibition. Next to the visitor paths, it is also possible to display a heatmap on the floor plan representing the overall amount of time the visitors spent at the exhibit (Figure 5). In addition to the visualizations, it is possible to browse a list of all log events regarding the selected AR tour and another list showing errors that occurred during the use of the AR tour.

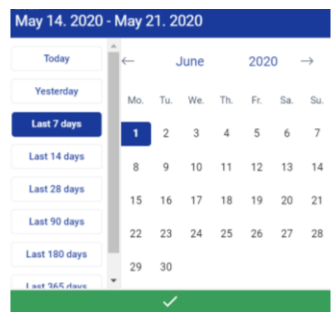

Figure 4: Selection of the displayed data *timeframe*.

4 Evaluation of the Visualization Interface

The visualization interface has been evaluated in two different usability studies. The first study was an interview at the end of the development phase. The second study was a usability questionnaire conducted with the real system running, where some of the feedback mentioned during the interview had already been implemented.

4.1 Interview

To get qualitative feedback regarding the system, an interview with museum professionals has been carried out. Two of the museum directors, who also took part in the initial interview before the development of the system, were asked to try out the system. The system was filled with demo data and the participants were asked to go through the individual views of the system and

[3] https://vuejs.org

Figure 5: Visualization interface showing visitor paths and a heatmap representing the time spent in different areas of the exhibition in a museum.

use the different functions according to a given list of tasks to complete. Then they were asked about the advantages they see using the system and how often they would like to use the system. Furthermore, they were asked which information and which functions they would like in addition to the data and views already provided by the current implementation.

4.2 Interview Results

During the interviews, the participants saw a great benefit using the system during exhibition planning. They mentioned that guiding and directing visitors are core topics that can be analyzed with the system. Another benefit of the system is the answer to so-called "highlights": *"What was ignored by the visitors?"* – *"Why are people attracted by that?"* – *"What are the interests of the visitors?"* Using the information of the system the exhibition can be changed to lead visitors to exhibits that previously were not noticed. The participants of the study mentioned that the system would be used approximately every two weeks or every month. Additional information that the participants would like to get from the system is age, gender, and information on where the visitors live. Information about the place of residence helps distinguish local visitors that might come regularly from one time tourists. Interesting information would also be a "dropout rate" calculated by checking the difference between the whole available playback time of the media and the total time of the presented media.

An additional feature that was asked for was a feedback form that visitors can use to rate and comment on each AR element they saw using the InfoGrid mobile app. The results can also be added to the visualization interface. At last, for the presentation at conferences, it would be useful to have the ability to export this information into CSV files, spreadsheets, or to provide an image export of the graphical results.

4.3 Usability Evaluation

The usability of the completed system has been assessed in a quantitative evaluation using the SUS questionnaire [18]. To analyze the affinity for technology Interaction of the participants the ATI questionnaire was used [19]. The study took place in a quiet room where only the participant and the evaluator were present. 11 participants took part in the study (5 females, 6 males). They had a mean age of 28.72 years (min. 20 years, max. 49 years, SD=9.22). A Mac Book Pro was placed on a desk for the participants to process the study. It was running a Chrome web browser instance in full-screen mode. Furthermore, an instruction sheet and an evaluation sheet were handed out to the participants. When the participants sat down at the laptop the procedure of the evaluation was explained to them. They were told that they will receive a sheet with tasks to complete. After completing the tasks, they would get another sheet where they can anonymously fill out the SUS and the ATI questionnaires [20].

4.4 Results of the Usability Questionnaire

The mean ATI score of the participants measured was 4.38 (Scale: 1 to 6; SD=0.71). The results indicate that the participants had an ATI score higher than the general population, which can be expected to be around 3.5 [20]. The usability score of the SUS test was 89.50 (Scale: 1 to 100; N=11) which is interpreted as excellent. [21].

5 Conclusions and Future Work

We presented the development and evaluation of a visualization system that can be used to analyze interactions with AR elements recorded using a mobile app. Museum professionals can use the system to upload a floor plan of their exhibition and to visually analyze, which paths single or a time-based number of visitors were inside their exhibition using the InfoGrid AR app. It can also be analyzed; whether visitors skip elements of the AR tour. We are also evaluating the possibility to combine the setup of the floor plan for the evaluation system with the setup of an interactive map, which visitors can use to find AR elements inside the exhibition.

The results of evaluations of the system indicate that it already reached an excellent level of usability. During the evaluation of the system, one participant mentioned he would like to get more information on the visitors, such as age, gender, and place of residence. This could be implemented by adding an optional questionnaire when starting the app. Another feature request of the participants of the study was the possibility to collect direct feedback on individual AR elements. The system can also be used to detect how much performance the mobile devices of their regular visitors have. This information can help to fit the performance needs of the interactive elements to the specifications of their own devices the users typically bring with them. Another interesting information would be the evaluation of the time between the interactions with the AR elements. The measured time can give hints about how long people are watching the physical exhibition. While our study focused on the context of museums and their staff, it can be assumed that the system might probably be used for the evaluation of AR tours in other applications and contexts as well.

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