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DEPARTMENT OF INFORMATION AND COMPUTING SCIENCES

GAME AND MEDIA TECHNOLOGY - MASTER THESIS

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# Joining Temporal and Geospatial Representations of Lifelogging Data.

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# Abstract

Lifelogging aims at recording daily data of your life. This is mostly done by wearing devices that can sense and record all kinds of data. A very important data type for lifelogging are images captured automatically by a body-worn camera. The resulting dataset is a huge number of images accompanied by some metadata. Exploring such a large dataset is quite challenging. It is often so large that the data becomes almost inaccessible. Therefore, much research has been done on the indexing and retrieval of lifelog images. While this is useful, if not essential for lifelog access, it is not sufficient because it lacks the opportunity to interactively explore and browse the data. This research therefore focuses on the exploration of such a large image corpus. Previous research suggests that virtual reality provides a lot of potential for free exploration of large image datasets. To visualize lifelog images, we therefore created a VR world that enables interactive exploration of such data. This environment makes use of the geographic metadata of the images and 3D imaging techniques, because previous work has shown that using a map-based approach can create useful and enjoyable browsing experiences. This research extends this approach by making use of the temporal component of lifelogging data by adding it to the filtering and clustering methods. We also use such time information to visualize the image set. A user study was performed to measure the usability of the system. It demonstrated that the visualisations further support the interactive exploration of the data.

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# Contents

<b>Abstract</b>	<b>1</b>
<b>Acknowledgements</b>	<b>2</b>
<b>Contents</b>	<b>4</b>
<b>Preface</b>	<b>5</b>
<b>1 Scientific Paper</b>	<b>6</b>
1 Introduction . . . . .	7
1.1 Lifelogging . . . . .	7
1.2 Lifelog Access . . . . .	7
1.3 Using Virtual Reality . . . . .	8
1.4 3D Visualization . . . . .	8
2 Related Work . . . . .	8
2.1 Lifelogging . . . . .	8
2.2 Virtual Reality . . . . .	8
2.3 Image Visualization in VR . . . . .	9
2.4 Lifelogging in VR . . . . .	9
3 Research Questions . . . . .	9
4 Implementation . . . . .	10
4.1 LSC22 Dataset and SQL Database . . . . .	10
4.2 Map-based Visualization . . . . .	11
4.3 Clustering . . . . .	11
4.4 Filtering and Wrist Menu . . . . .	11
4.5 Timeline . . . . .	12
4.6 Performance measures . . . . .	12
5 User Study . . . . .	13
5.1 Objectives . . . . .	13
5.2 Materials and Set-up . . . . .	13
5.3 Method and Procedure . . . . .	13
6 Results . . . . .	14
6.1 Participants . . . . .	14
6.2 User Experience . . . . .	14
6.3 Timeline Visualisation . . . . .	15
6.4 Filters . . . . .	15
6.5 Clustering . . . . .	16

7	Discussion . . . . .	16
8	Conclusion . . . . .	16
9	Future Work . . . . .	17
	Bibliography . . . . .	17
	<b>Annotated Appendix</b>	<b>20</b>
	<b>A Literature Study</b>	<b>21</b>
A.1	Lifelogging . . . . .	21
A.1.1	Main Features . . . . .	21
A.1.2	Metadata . . . . .	22
A.1.3	Big Data . . . . .	22
A.1.4	Exploration . . . . .	22
A.1.5	Conclusion . . . . .	22
A.2	Virtual Reality . . . . .	22
A.2.1	Uses for Virtual Reality . . . . .	23
A.2.2	Data Analysis in VR . . . . .	23
A.2.3	VR for Lifelogging Data . . . . .	23
A.2.4	Conclusion . . . . .	23
A.3	Image Visualization in VR . . . . .	24
A.3.1	Geographic Visualization . . . . .	24
A.3.2	Globe Visualization . . . . .	24
A.3.3	Timeline Visualization . . . . .	26
A.3.4	Film Roll Visualization . . . . .	26
A.4	Memory Storage and Retrieval . . . . .	27
A.4.1	Shoebox . . . . .	27
A.4.2	MyLifeBits . . . . .	27
A.4.3	Geographic Lifelogging Systems . . . . .	27
	Bibliography . . . . .	28
	<b>B Implementation Design</b>	<b>30</b>
B.1	Main . . . . .	30
B.1.1	SQL Setup . . . . .	30
B.1.2	Map Design . . . . .	30
B.1.3	Image Clustering . . . . .	32
B.1.4	Image Filtering . . . . .	32
B.1.5	Timeline Design . . . . .	33
B.1.6	Content Menu . . . . .	33
B.2	Tutorial . . . . .	35
	<b>C User Study Design</b>	<b>37</b>
C.1	Pre-test . . . . .	37
C.2	Participants . . . . .	37
C.3	Evaluation Plan . . . . .	37
	<b>D Participant Statistics</b>	<b>40</b>
	<b>E Survey</b>	<b>44</b>

# Preface

This thesis was done as part of the master program Game and Media Technology at Utrecht University. It addresses the visualization of lifelog data in virtual reality (VR) and is entitled *Joining Temporal and Geospatial Representations of Lifelogging Data..* It consists of two parts:

- A scientific paper that presents the scientific research done for this thesis and the outcomes and conclusions.
- An annotated appendix that contains additional information beyond the major results presented in the scientific paper:
  - A literature study that was carried out to explore the different research domains that this project touches.
  - An extended design description of the VR implementation.
  - An extended description of the user study.

Further contributions of this thesis project, that are not presented in this document include:

- All the source code for a renewed VR implementation which provides a good basis for follow-up research in this domain.
- All the raw data gathered during the user studies.

# Chapter 1

## Scientific Paper

This chapter contains the scientific paper. It outlines the complete research of this MSc Thesis in a paper format.

# Joining Temporal and Geospatial representations of lifelogging data.

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## Abstract

Lifelogging aims at recording daily data of your life. This is mostly done by wearing devices that can sense and record all kinds of data. A very important data type for lifelogging are images captured automatically by a body-worn camera. The resulting dataset is a huge number of images accompanied by some metadata. Exploring such a large dataset is quite challenging. It is often so large that the data becomes almost inaccessible. Therefore, much research has been done on the indexing and retrieval of lifelog images. While this is useful, if not essential for lifelog access, it is not sufficient because it lacks the opportunity to interactively explore and browse the data. This research therefore focuses on the exploration of such a large image corpus. Previous research suggests that virtual reality provides a lot of potential for free exploration of large image datasets. To visualize lifelog images, we therefore created a VR world that enables interactive exploration of such data. This environment makes use of the geographic metadata of the images and 3D imaging techniques, because previous work has shown that using a map-based approach can create useful and enjoyable browsing experiences. This research extends this approach by making use of the temporal component of lifelogging data by adding it to the filtering and clustering methods. We also use such time information to visualize the image set. A user study was performed to measure the usability of the system. It demonstrated that the visualisations further support the interactive exploration of the data.

## 1 Introduction

### 1.1 Lifelogging

Lifelogging is known as the recording of one's personal life. For hundreds of years people have tried to find ways to record their memories and store them in safe places [1]. Lifelogging is a result of these pursuits. It is mainly understood as the continuous recording of data during the day. A more unambiguous description of lifelogging can be given as follows:

*"The process of passively gathering, processing, and reflecting on life experience data collected by a variety of sensors, and is carried out by an individual, the lifelogger" [2].*

In this definition three aspects in handling lifelogging data are defined, namely gathering, processing and reflecting. In this study the focus is on last of the three, namely reflecting.

One of the most important parts of lifelogging is capturing image data. The image data consists of photos taken automatically, for example, every 30 seconds, often by a body worn camera. What sets it apart from other recording methods, is the capturing of additional metadata. The scope of this metadata can be quite large. This makes the collected dataset more than a digital archive. The collection becomes a recording of one's memories. Since the recording of both the images and metadata takes places without the carrier's intervention it contains no bias and becomes a recording of all personal events.

### 1.2 Lifelog Access

Reflecting on lifelog data is here defined as accessing the contents within the collected data set. Since lifelogging creates such a large amount of data, accessing



it is not a trivial task. The retrieval and indexing of such a large amount of images has been researched extensively [3]. This type of research mostly focuses on system performance for targeted search tasks. However, this study focuses on the exploration of lifelog data, as this is also an important, complementing way of reflecting on the collected data. Examples of such scenarios include the exploration of a pre-filtered data set, such as exploring all photos taken on a certain day or during a particular vacation, and browsing a data set without a concretely defined search goal, such as: "What did we do on the day trip to Brussels that we took 15 years ago?" or "When did I visit the beach last year?" The design and development of an application capable of this is a certainly a challenge on its own [4]. Virtual Reality (VR) is offered as a tool to tackle this challenge.

### 1.3 Using Virtual Reality

As datasets get bigger and bigger, it become increasingly difficult to visualize them, especially with the limitations imposed by 2D interfaces. VR gives new design options in two helpful ways. Firstly an extra dimension becomes available, enabling 3D visualization techniques which are able to show more data to the viewer and present it in different ways. Secondly, VR enables a whole new way of interacting with media. For example, a user can observe data freely from multiple perspectives and interact with it directly. This could provide better insight into the data and possibly enhance the experience of data exploration.

### 1.4 3D Visualization

As stated before, VR enables an extra dimension in visualization. Previous work [5] [6] has shown that a map-based 3D interface has high potential for the visualization of lifelogging data because the geo-spatial component plays an important role in people's memory and visualizes valuable meta information about a lifelog image. Yet, there are many other aspects that can play an important role when exploring ones lifelog data, ranging from the actual content of images to meta data such as at what time a picture was taken. The aim of this study is therefore to extend an existing geospatial VR representation of lifelog data with other information to further improve the ability of users to

explore it. A particular focus is the addition of temporal information.

The structure of this paper will be as follows. Section 2 will discuss the background information for this paper. Section 3 details the research questions for this research. Section 4 talks about the implementation of the VR application. Section 5 details the user study done to evaluate the application and Sections 6 and 8 discuss the outcomes of this research. Afterwards possibilities for future research are discussed in Section 9.

## 2 Related Work

In this section we will discuss the previous work related to this research and look at ideas and insights from related research fields, which give useful knowledge and inspiration for this research. Four related research fields have been identified as the most relevant for the design choices in this paper and are addressed in this section.

### 2.1 Lifelogging

Lifelogging is a way of performing *sousveillance*: the personal documentation of ones live [7]. There are multiple ways in which lifelogging can be performed. Such as image capturing and video recording among others.

One key characteristic of lifelogging is that it generates a large amount of data. This make it a big data application, which have their own set of challenges [2]. For lifelogging these are defined as volume, variety and veracity. A second characteristic of lifelogging data is the imperfection of the data. Data might be missing or incomplete and this needs to be taken into account when designing a system meant to explore such data. Another important characteristics of lifelogging data is the metadata. This additional data allows itself to be exploited in a way that is useful for the users. Recent research shows that there are still numerous challenges and opportunities in this field [8] [9]. While research mainly focuses on the retrieval of data [10], this study keeps its focus on the exploration of data.

### 2.2 Virtual Reality

From the beginning of its development, VR has shown to have its uses in several applications. The technology is often used in entertainment, like video games or

movies [11]. This does not mean, however, that entertainment is its only purpose. VR has shown countless times that it has beneficial applications in other industries, such as simulations, medical fields, or engineering [12]. Nowadays, VR technology comes in many different forms, making it more accessible than it ever was. The most popular forms of VR are Head-Mounted displays (HMDs). These are goggles worn on the head. These displays allow standalone applications to be run directly on the headset. There is also onboard memory, capable of carrying data such as that obtained during lifelogging.

The opportunities that VR provides, can also be useful in the research field. VR technology has shown that it offers a new approach to explore data [13]. The extra dimension and heightened immersion of VR has the potential to create a more intuitive visual comprehension of the research data. This can be especially beneficial for larger data sets [14].

While the above points hold true for the general use cases described, it is important to also study the effectiveness of VR for lifelogging specifically. To reiterate, a lifelogging dataset is a large image corpus with associating metadata. Image browsing is a common feature on most VR devices. Research has also shown that VR is an intuitive way to explore images [15]. Early research showed the viability of a lifelogging platform in virtual reality [16]. Frameworks for lifelogging system design also already exist [17]. One was also made specifically for VR [18], showing viability of the platform.

### 2.3 Image Visualization in VR

Visualization of a large image corpus is no trivial feat. Many studies have been performed to find appropriate ways to solve this problem. This study focused on VR, so the visualization has taken into account the 3D space the viewer is observing from. A good way to visualize data is important, as it is necessary to properly explore and evaluate the data. Several visualizations have been considered, in this section we will only explain the methods that have been used in the implementation.

A geographic representation is the main representation upon which our system is build. The images are presented on a map, based on their geographic location. Previous research using this techniques showed that it is useful and applicable in the lifelogging research field [5] in situations where the geospatial information plays

a role in the search and exploration process.

Various other 3D visualisations of images have been researched, which are all usable in VR as well [19][20][21]. This study is aimed at exploring whether such 3D visualisations work for lifelogging data in VR too. Another study [22] has shown the effectiveness of various timeline designs. Lifelogging data has a strong chronological characteristic. This means that it is very likely to be a very intuitive approach to explore the data which is why the integration of temporal information into the existing geospatial visualization is a main focus of this research.

### 2.4 Lifelogging in VR

Previous research on how to visualize and access lifelog data in VR has addressed different aspects of this problem. Some tested the use of the geospatial data [23]. This work shows that a VR program based on this idea can work to make lifelogging data accessible. Yet, it is limited to provide access solely via the geospatial information. Which is why another study explored the addition of tag filters to the system [5]. A study from Van Abeelen [24] added to this program by including the temporal component of the metadata. This work showed how a temporal component can add to the original program and how new metadata can be added. The addition of the temporal component has also been studied in 2D applications [25]. Here it was shown what the possibilities and limitations are for the use of the temporal data. These observations are important to keep in mind for this system which aims for a similar goal but uses different approaches and visualizations to achieve it.

## 3 Research Questions

In this study we have created a system that allows people to interactively explore lifelog data. In such a system it is important that it allows users to fully explore the dataset and find the information that they are looking for, but it is also important that this exploration allows users to find information that they themselves perhaps forgot existed. Section 2 illustrated that a geospatial representation of lifelog images in VR can be a good first step towards achieving this goal, that is, to represent the data to the user in a way that makes it easy and

engaging to explore. There is however other metadata available which can be very helpful in an exploration scenario. Information such as temporal metadata, but also image content description. For exploration, the way the information is presented to a user is also important. This included visibility, but also context. For example, a timeline of images provides more valuable information than a random sequence of images. Clustering could also be is an important tool in this aspect of the system, as lifelogging means dealing with a large number of images.

In this study we build on the existing work of geospatial lifelog visualization in VR and extend it using these assumptions. In particular, we look into how temporal information can be added into this system in a way that is beneficial for an exploration focused user. There will also be an addition based on the visualization. This will make use of the VR aspect of the system and clustering techniques when showing the actual images to the user. These additions need to be helpful for the purpose of exploration. Because of the informal character of exploration tasks, it is also important that the inclusions improve enjoyability and usability.

These goals are achieved by answering the following research questions:

1. How well does our clustering and temporal filtering approach enable users to explore known and unknown lifelog data?
2. How well does our timeline visualization enable users to explore known and unknown lifelog data?
3. How enjoyable and user-friendly is our system?

Extensions of a system puts a higher strain on system performance which in turn can have an impact on usability and enjoyability Hence, related restrictions must be considered in the design of new solutions. Therefore, we have evaluated these restrictions by answering the following engineering-related questions:

4. How many photos can be displayed at a time without having a negative impact on user experience?
5. How fast can we exchange photos if a change in visualization is required (e.g., due to applying a new filter or changing the perspective of a visualization)?

## 4 Implementation

In this section, we provide an in-depth description of the technical aspects and development process of our VR lifelogging data browsing application, implemented using Unity3D. We discuss the software and hardware components, development tools, and methodologies employed to create an immersive and interactive experience for users. The application was developed using the following development environment:

- Unity: The game engine Unity was chosen as the main development platform, due to it’s accessibility in VR development. The version used in this research was Unity 2022.3.6f1 LTS [26].
- Meta Quest 1: To ensure compatability with most headsets, the Oculus Quest 1 was chose as it is an older model and if the application runs on this headset, it should run on newer models as well [27].
- C# Scripting: The application logic and interaction were implemented using C# scripts in Unity.
- SQLite Database: We employed an SQLite database to store metadata and indexing information for lifelogging data, providing efficient data retrieval and search capabilities [28].

### 4.1 LSC22 Dataset and SQL Database

The dataset used in this study is the LSC 2023 dataset [29]. The dataset contains the images and their corresponding meta data. In total, the dataset contains more than 700,000 images, which have been taken between the April 1st, 2019 and May 30th, 2020.

The dataset also includes two CSV files. The first contains the metadata of the images, such as time and location. The second contains the visual concepts of the images. These are tags that describe the image content.

Using scripts made in Python, they have been transformed into an SQL database which can be queried by the system. Figure 1.1 shows how the database is set up. In this setup image information can directly be retrieved using a single SQL command.



Figure 1.1: Diagram of the SQLite database.

## 4.2 Map-based Visualization

The main feature of the application is the map-based, which is based on the version developed in [5]. For this study, an updated version was created which improved the original map visualization by adding the following two features:

- **Multiple zoom levels:** This feature was implemented to increase visibility of the map when the player wants to see an overview of the map. For better usability, it is important that users can explore the map and images located on it at different levels of granularity. For example, from further away to get a good overview of where the lifelogger has been, and very close and detailed when examining images in a concrete area of interest.
- **Dynamic Loading:** This feature prevents the entire map and database to load at once. Areas are loaded as users move around, increasing overall performance. We expect that this also improves usability by reducing waiting time for necessary system updates during exploration.

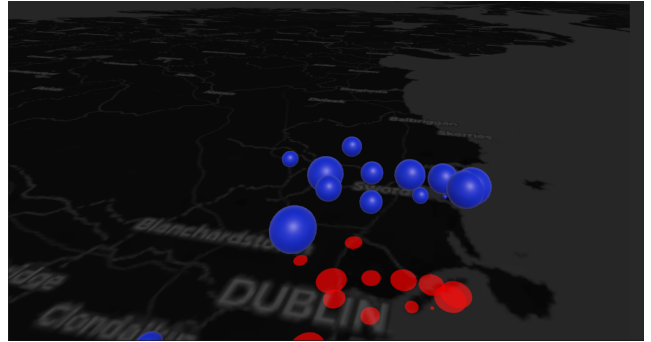


Figure 1.2: Screenshot of the map.

## 4.3 Clustering

In the previous system, each single image from the database was represented via an individual label on the map at the location it was taken. This quickly leads to an overload and clutter at locations with many images. To prevent this, the extended version does not present individual images directly but shows location-related clusters. These clusters are made using a K-means clustering algorithm based on their coordinates. K-means was used because it is easy to implement, yet very suitable for a geographic application. The clusters' size is dependent on the amount of images inside. This gives the player some information while they are exploring the dataset. To increase visibility, the size of a cluster also increases proportionally to its original size when the player moves away from the. An example of these clusters is shown in Figure 1.2.

## 4.4 Filtering and Wrist Menu

Filtering the data according to some criteria is an established way to reduce the size of a visualized data set and ease its exploration. The existing system has been extended to support filtering in two ways. Firstly, the content can be filtered using the temporal components. Content is divided into their months and users can select which months they want to explore. This is done by using the ImageID in the SQL database. We expect this feature to be very valuable for data exploration because people often associate events with moments in time (e.g., "I visited that restaurant last June."). Likewise, there are often situations where people want to see what they did at particular moments in time (e.g., "What did I do on my business trip last year?").

Secondly, the content is filtered using the visual concepts. A separate tags database was created from the metadata which connects the correct tags to the individual images. Now SQL queries can be executed which look for specific image content. Because the provided set of tags is very large and diverse – ranging from very high level concepts to very specific and unique descriptions – a selection has been made of the tags that are used in the application. This selection cover almost all images, without cluttering the menu. This work is just to verify the general usefulness of such tags and how they can be integrated into the overall system design. Exploring what type of tags are the most suitable and how to create them is beyond its scope and should be addressed in future work.

Filters can be selected using a menu located on the wrist of the user. Two menus are present, one contains the buttons for selecting the tag filters and one contains the buttons to select the month filters. Figure 1.3 shows the final version that was implemented.

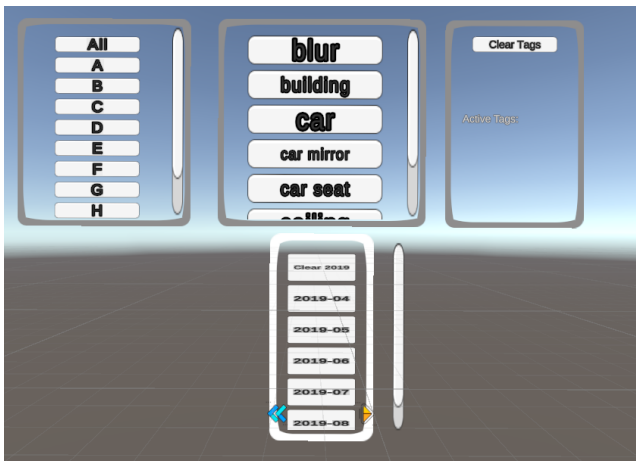


Figure 1.3: Screenshot of wrist menu.

## 4.5 Timeline

Even with time-based filtering and geospatial clustering, there are often quite a lot of images located within an individual cluster. Another extension of the existing system is therefore a timeline-based visualization of the images once users select a single cluster.

In this visualization, images are displayed in chronological order. The images follow one after the other and form a spiral around the user. Users can explore the

images along the timelines by turning their head or walking around in the environment. Figures 1.4 and 1.5 illustrate a view from the inside, which is the initial view after selecting a cluster, and outside after the user was navigating in the environment. In addition, users can interact with the timeline directly. Dragging it left or right changes which portions of the timeline are shown right in front of them, allowing users to explore consecutive images along the timeline. Likewise, they can drag it up and down in order to move different intervals from the timeline into their field of view.

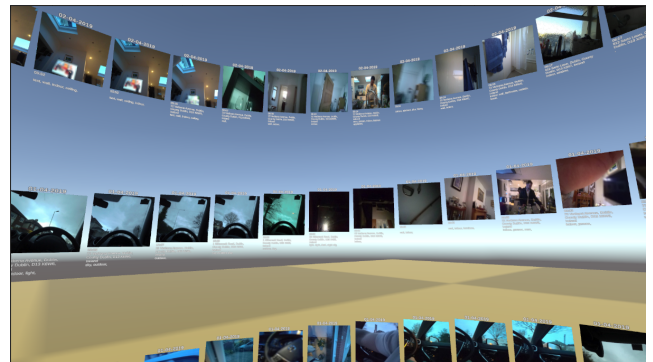


Figure 1.4: The timeline visualization from the inside.

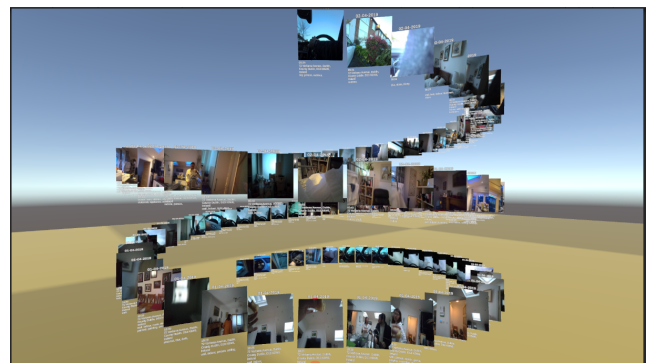


Figure 1.5: The timeline visualization from the outside.

## 4.6 Performance measures

Adding the functionality described above puts a high strain on system performance, requiring us to make compromises in the number of photos that can be displayed at a time and swapped when, for example, the user is moving around. We specified these two requirements via two engineering questions in Section 3.

First the answers for the engineering questions are given. The results for these questions were obtained by running simulations in Unity and displaying these on the headset. To re-iterate, we wanted to know how many photos can be displayed at a time, and we wanted to know how fast photos can be exchanged if a new query is executed.

Table 1.1a shows startup times on a new scene with a fresh db connection. These are measured from startup until the last images is displayed.

Table 1.1b shows the time it takes to refresh the query. This is an indication of the switching speed of the clusters. This is measured from removal until the new set is completely displayed.

From these results we can see that there are some design limitations for the system. It can only show around 2000 images at a time. Because replacing all of them at once will result in a noticeable and unacceptable delay the images are loaded dynamically in the background when a cluster is opened. This means that the images are not loaded at once, but one after the other, using parallel computing. In this way the lag in the system does not interfere with the controls of the user.

## 5 User Study

This section describes the user study that was carried out to evaluate the new, extended and revised lifelogging application by answering the research questions specified in Section 3. The objectives of the user study are outlined. The set-up and methodology is explained after that and also a summary of the participants of the study is given.

### 5.1 Objectives

The main objective of this user study is to answer research questions 1, 2, and 3. To do this, participants explored the lifelogging data of the LSC22 dataset introduced in Section 4.1, using the application. Afterwards, they filled out a survey about this system and their experience with it. During the evaluation several statistics are tracked which give more information about how the application is used. These statistics include time spent in the application and what buttons the participant pressed at certain times. The research

questions are then answered through the results of this survey and the tracked data.

### 5.2 Materials and Set-up

The experiments were performed in a quiet and neutral room. Participants followed a convenience sampling and were recruited via word of mouth. Participation was voluntary and subjects were not reimbursed or rewarded for their participation. Before the VR test, participants signed a consent form and were asked to fill out a small questionnaire, which asked for some information about the user that could influence the test, such as eye deficiencies. It also asked about their experience with both image systems and map systems. After this was done, the participants were asked to put on the headset and start the test. During the test, the participants were guided through the test by the test coordinator. The exact details of this procedure are explained in the next section.

After the VR test, participants filled in a survey. First their experience is measured using the SUS matrix [30]. This is a matrix often used to measure usability. After that participants filled out whether they experienced any cyber sickness symptoms. The survey contains a list of common symptoms. [31] In the end participants could fill out what they liked and did not like about the system. This feedback was then used to measure the usability of certain features. The questionnaire and survey can be found in Appendix E

The application was run from the Unity environment which streamed it to the headset. The PC used to run the application contains a AMD Ryzen 5 5600X, NVIDIA GeForce RTX 3060 and 40 GB memory. The test coordinator can observe what the participant is seeing via a monitor.

### 5.3 Method and Procedure

As explained, participants were first asked to fill out a short questionnaire and to sign a consent form. After this was done, participants were asked to put on the VR headset. They then had a chance to adjust the headset to their liking and make sure the screen was in focus.

The test first starts with a tutorial. This part consists of four sections. Each section explains the controls of a key feature of the application. There is also a control scheme on display for reference. After the par-

Amount	Time [s]	Crash
4000	58	yes
2000	29	no
1000	7.3	no
500	3.8	no

(a) Results of system loading times

Amount	Time [s]	Crash
2000	51	no
1000	10.6	no
500	7.8	no

(b) Results of system query times.

Figure 1.6: Engineering test results

participant has completed each tutorial section, they may begin the actual test.

In the test, the participant starts elevated above the map. During this test five questions have to be answered. This is done by finding one picture that answers the question correctly. The following five questions were used in this evaluation:

- A In what city does the subject most likely live?
- B Can you find a picture of a place abroad where the subject has travelled to?
- C Can you find a picture where the subject was near the sea.
- D Can you find a picture where the subject was having lunch?
- E Can you find a picture where the subject is working?

The questions were asked in a random order. For each question the order, the answer and the time it took to find the answer was recorded. The questions were asked by the test coordinator, who was present during the whole evaluation. The participant answers the question by saying it to the coordinator and showing the image on the screen. The coordinator noted the answer and the time it took to complete it using the measurement tool in the application.

## 6 Results

This section shows the results obtained from the user study. The results are divided by the features that were investigated in this study.

### 6.1 Participants

In total 11 participants took part in the evaluation. This amount was deemed to be satisfactory, as newer participants did not give new insights or data [32]. Saturation was checked in regards to the SUS score. Which shows that new participants do not influence the score much, which made it possible to end the evaluation phase. [33]. The general statistics of the participants can be seen in Appendix D.

### 6.2 User Experience

The average SUS score for the participants was 56.4 with a standard deviation of 15.9. This is lower than the score obtained in previous research. Looking at the feedback that participants gave the system, this is mainly due to the difficult controls and the hardware limitations. If a new query is executed there is still a small pause in the application. This is very short (< 1 second), but still disrupting when wearing the VR headset.

Participants were also asked to report on any possible cybersickness symptoms they experienced. The reported occurrences can be seen in figure 1.7. The amount of occurrences is relatively low, indicating that the program did not hinder user enjoyment in this way.

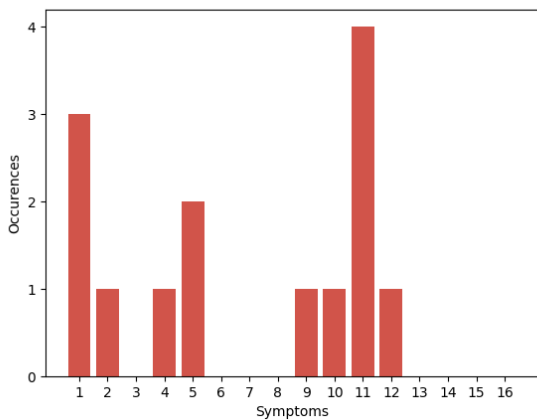


Figure 1.7: Cybersickness occurrences

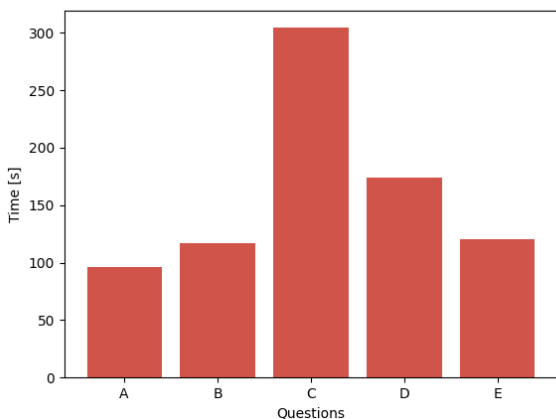


Figure 1.8: Time to complete each question.

### 6.3 Timeline Visualisation

Participants were asked what they did and did not like about the system in question 13 and question 14. Regarding the timeline, participants gave mostly positive feedback. Participants were not asked directly about certain features, as to not influence them on what feedback would be given. Even though they were not asked directly, four participants gave positive feedback on the timeline visualization. Two participant noted that they like the timeline and that it benefited their immersion in the system. One participant said that it helped them

explore the timeline and that it *“made it easy to see what the person was doing at that moment”*.

Two participants gave negative feedback about the timeline. One noted that it made navigation more difficult. The other found it disorganized. No other participants had anything to say about the visualisation.

It is worth noting that all participants managed to find correct answers to the questions. Which was not always the case in similar systems. Figure 1.8 shows that it was also done in a reasonable time. Observations during the test, as well as comments in the feedback show that the participants did use the timelines to successfully find answers. This was especially visible in question D, *“Can you find a picture where the subject was having lunch?”*, because this questions has a strong temporal component in *“lunch”*. Thus, combining these findings with the feedback from the participants, we can see that the visualisation does help users explore the lifelogging data.

### 6.4 Filters

The first clear observation regarding the filters is their importance in the current implementation of the system. Figure 1.9 shows how many times certain buttons on the Quest controllers were pressed in total by all participants. The peak in interactions is for the right trigger button. This button was assigned to menu selection. The button was also used for flying up, but the difference between the right and left trigger (flying down) shows that most interactions come from the menu selection. This importance is also seen in the survey answers. As one participant noted that the filters were very important to keep an overview of the system. In total six participants gave feedback about the filters or the menu.

Two participants noted how the filters helped them find the answers they were looking for or other interesting content. One participant mentioned how they liked the interaction between the map-based interface and the filters.

Two participants had noted negative feedback about the filters. Aside from feedback about the design, one participant explained that there were not enough filters to their liking. This was due to there not being a tag for the object they were looking for. As explained before this was designed on purpose, but this shows that it is still a limitation of the current implementation



We can observe from this that people did like to use the filters and that it did help them navigate the dataset.

## 6.5 Clustering

In total four participants gave feedback about the clustering feature in the system. All four indicated that the clusters helped them navigate the data and find what they were looking for. Two indicated that the cluster orbs helped them to find where they needed to look for the images. Two noted that the sizing of the orbs helped them in their exploration of the dataset.

From all participants only one gave negative feedback about the clusters. This was only about the design of the clusters and a bug that occurred during their test.

The map-based interface allows people to get an overview of the data. Figure 1.10 shows at what height users spend their time. One reason users do not travel above the map as much might be because the clusters already give them an overview. It allows them to easily see where images are without looking at the whole map.

These observations do indicate that the clustering helps users in exploring the data. Especially when the users have no insight into the data. The clustering and the added features give a lot of information to the users, which they can use in their search.

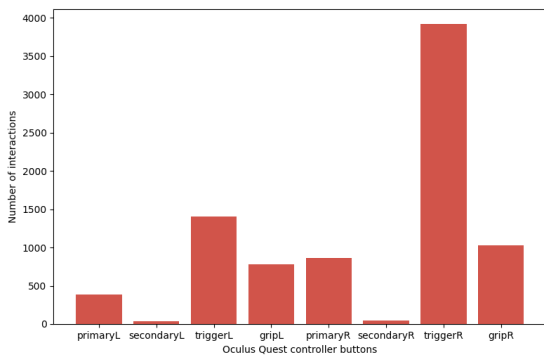


Figure 1.9: Button presses of the participants.

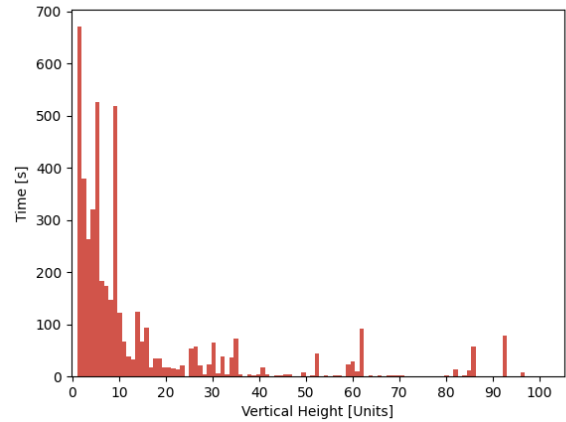


Figure 1.10: Time spent of users at certain heights.

## 7 Discussion

From the results we can answer the research questions proposed earlier.

*How well does our clustering and temporal filtering approach enable users to explore known and unknown lifelog data?*

The results show that this approach enables the exploration quite well. It makes it easier and more approachable for users to find data, even if they do not specifically know what they are looking for.

*How well does our timeline visualization enable users to explore known and unknown lifelog data?*

From the results we can see that the timeline does enable users to explore the data. Not only does it allow users to get an overview of the data inside a cluster. It also allows users to view the data in a more granular approach, where they can observe each image individually.

*How enjoyable and user-friendly is our system?*

The system is measured to be enjoyable and user friendly. Participants of the user study note it to be a positive experience overall, even though there are still improvements to be made in the VR performance.

## 8 Conclusion

In this paper we demonstrated an implementation of a map-based image browsing system. We implemented

a 3D visualisation technique to enable users to explore lifelogging data. A clustering based on geological data and filtering based on temporal data were implemented in the system. A user study was done to see whether these features enable people to explore lifelogging data. In the user study the usability and user-friendliness were investigated as well. The scores and feedback obtained from this study show that these features further enable exploration of the data in the the map-based implementation

## 9 Future Work

Based on the outcomes of this research, the following items are suggested for future work:

- In order to get a first idea if clustering is helpful in this context at all, a rather simple K-means clustering was implemented. Given the positive responses about the usefulness of clustering in your user study, future work could explore more sophisticated clustering techniques.
- While some users were positive about our timeline visualizations, others mentioned drawbacks and issues with it. Our results therefore show that they are a step in a promising direction, but further modifications and also the evaluation of different visualizations should be investigated.
- The current time filters are still quite broad which led into some complaints from users in the study. Yet, there overall relevance and usefulness was clearly prove, which is why future research could look into the more granular research approaches.
- Despite the performance optimizations and limitations on the number of images displayed at a time, the system still occasionally suffered from time delays. More powerful hardware as well as further optimizations could help dealing with this problem and enable a more dynamic system.
- Based on the numerous reactions to the survey question "What do you think this system could be used for?", it might be interesting to see how a system similar to this might work for other datasets, such as a database with surveillance footage [34]. Since many participants noted that such a system could be interesting for investigative purposes.

Aside from these recommendations future work on this system, which directly resulted from our observations, one might want to improve the performance in general and look at additional features to add, or explore the use of additional metadata.

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# Annotated Appendix

This appendix contains further relevant information from the work done for this thesis. Appendix A contains the literature study performed at the beginning of this research. Appendix B discusses more details about the design of the application. Appendix C explains the setup of the user study. Appendix D shows the statistics of the participants of the user study and Appendix E shows the survey used in said study.

# Appendix A

## Literature Study

This appendix will concisely discuss the literature study performed in the first phase of this thesis.

The first section will discuss the field of lifelogging. This research topic was studied thoroughly as it is a core part of this thesis project. Next, section 2 is dedicated to the application of virtual reality (VR) in lifelogging research. This helps to narrow down the broad topic and focus on the parts important to this study. Section 3 focuses on visualization techniques in VR. Data can be shown in many ways, a literature study of this topic was necessary to explore viable options. Finally, section 4 discusses the papers of similar systems and the recommendations their authors gave.

At the end of each section a short conclusion is given. This will explain what is important to take into account when performing the study.

### A.1 Lifelogging

Lifelogging is a way of performing *sousveillance*: the personal documentation of ones life [1]. There are multiple ways in which lifelogging can be performed. This section is meant to summarize the literature review of the lifelogging research field. The main features and characteristics are described and the main challenges are laid out. This is done to establish a framework to develop the eventual system in.

#### A.1.1 Main Features

The most important part of lifelogging is capturing image data. The image data consists of photos taken automatically, usually by a body worn camera. What sets it apart from other recording methods is the capturing of additional metadata. The scope of this metadata can be quite large. This makes the collected dataset more than a digital archive. The collection becomes recording of one's personal events. Since the recording of both the images and metadata takes places without the carrier's intervention it contains no bias and becomes a recording of all conscious and unconscious memories. The dataset behaves like a film roll filled with snapshots of a person's experiences. This and the metadata are important features to take advantage of when designing a system to explore the data.

### **A.1.2 Metadata**

In lifelogging a lot of different metadata can be collected. This study makes use of the LSC 2023 dataset [2]. This dataset does not only contain the actual images taken, but also the accompanying metadata. The images are taken automatically by a carry-on device with approximately 35 seconds between them. The associated metadata is also stored at that moment. Two types of data are stored. One type concerns time, location and physical activity. The second type describes the content of the image. Computer vision programs were used to classify the content of each image. Here several tags are assigned to each image. The main reason the metadata is so interesting, is that it is useful to use this to present the images in a meaningful way. The geo-location data and the temporal data will be heavily used in this study, but the other components might provide extra insight into the dataset.

### **A.1.3 Big Data**

A key characteristic of lifelogging is that it generates a large amount of data. This makes it a big data problem, which has its own set of challenges [3]. For lifelogging these are defined as volume, variety and veracity. Volume makes the exploration of the data difficult. It also creates problems when storing and retrieving the images. Variety is a problem because there are a lot of different types of data. Aside from the images there is metadata to account for. This also creates opportunities as it allows us to work with this data to present the images. Veracity refers to the accuracy of the data. In this case it refers to both inaccuracies in the metadata as the quality of the images themselves. In the end the content of the dataset is not set to a perfect standard and this has to be taken into account when handling the data. All the challenges described by the characteristics are important to take into account when designing the system.

### **A.1.4 Exploration**

As explained before, lifelogging data on its own is difficult to find specific images or general exploration. Much research has been done on retrieval systems of lifelog data [4] [5] [6]. It is important to distinguish the challenges that arise during retrieval from the challenges that occur in an exploration focused scenario. In this system it is important to enable access to all images. The viewer does not necessarily know what they are looking for in the data, so all data must be accessible, which quickly becomes a big data problem. The problem can be minimized by filtering or clustering before the user accesses the data. Unnecessary and/or confusing data can be subdued by the system, which makes exploration easier as a result.

### **A.1.5 Conclusion**

In this section the concept of lifelogging has been discussed. The key characteristics of lifelogging, such as its metadata, offer opportunities which can be exploited in a novel exploration system. Studies have identified several challenges that arise when handling lifelogging data. These are important to keep in mind when designing a usable system.

## **A.2 Virtual Reality**

This research focused on the application of VR for the exploration of lifelogging data. This part of the literature review is required to verify whether VR is even a viable tool for this purpose.

### **A.2.1 Uses for Virtual Reality**

From the beginning of its development, VR has shown to have its uses in several applications. The technology is often used in entertainment, like video games or movies [7]. This does not mean, however, that entertainment is its only purpose. VR has shown countless times that it has beneficial applications in other industries, such as in simulations, medical fields, or engineering [8]. Nowadays VR technology comes in many different forms, making it more accessible than it ever was. The most popular forms of VR are Head-Mounted displays (HMDs).

### **A.2.2 Data Analysis in VR**

The opportunities that VR provides, can also be useful in the research field. VR technology has shown that it offers a new approach to explore data [9]. The extra dimension and heightened immersion of VR has the potential to create a more intuitive visual comprehension of the research data. This can be especially beneficial for larger data sets [10]. The challenges of Big Data already occur in the processing of the data, like issues with collection, analysis and representation. Virtual reality shows that it can have a meaningful impact in these fields.

Trying to observe or analyze data mostly means to look at it on a screen. This gives a 2D representation of the data. This physical limit is opened up with the use of VR technology. In 3D space, the data can be freely observed and analysed. Research has shown that this method of observation allows the observer to not only take in more information, [11] but also to take it in more accurately [12].

### **A.2.3 VR for Lifelogging Data**

While the above points hold true for the general use cases described, it is important to also study the effectiveness of virtual reality for lifelogging specifically. To reiterate, a lifelogging dataset is large image corpus with associating metadata. Image browsing is a common feature on most VR devices. Research has also shown that VR is an intuitive way to explore images [13]. Early research showed the viability of a lifelogging platform in virtual reality [14]. Frameworks for lifelogging system design also already exist [15]. Such a framework has also been made specifically for VR [16], showing the viability of the combination of VR and lifelogging.

This work has built upon work done in previous theses. This is the work done by Ouwehand and Mengerink [17] and the work done by van Abeelen. [18] The former work consists of a program made for accessing lifelogging data using the geospatial metadata. Since their work showed that such a VR application can work to make lifelogging images enjoyable and intuitive to browse, this makes it a good starting point for the work in this study. Van Abeelen added to this program by including the temporal component of the metadata. While this work has not been directly worked upon, it does show how new metadata can add to the original application.

### **A.2.4 Conclusion**

In this section the use of virtual reality in lifelogging systems was discussed. This knowledge is particularly crucial to the project. Research on VR technology has shown that it can be used for problems concerning big data, which is a part of lifelogging. It has also been shown that VR offers several benefits over 2D representation in some scenarios. Previous papers on the use of VR lifelogging exploration has shown both the opportunities as well as the limitations of the technologies. This is important when considering the design of the system in this project.





Figure A.1: Early prototype of the map zoomed in.

## A.3 Image Visualization in VR

Visualization of a large image corpus is no trivial feat. Many studies have been performed to find appropriate ways to solve this problem. This study focused on virtual reality, so the visualization will take into account the 3D space the viewer is observing from. A good way to visualize data is important, as it is necessary to properly explore and evaluate the data. This section will discuss the several visualization techniques that are a possibility to be used in the system. Every technique is tested for its feasibility with a small prototype.

### A.3.1 Geographic Visualization

This is the main representation upon which the system is built. The images are presented on a map, based on their geographic location. Previous research using this technique showed that it is useful and applicable in the lifelogging research field. [19] In this work a map is rendered. On the map waypoints are shown that give an indication of where the images are taken. Important features of this technique are zooming and clustering. Navigating is done in VR through teleportation, flying and walking.

The prototype, as shown in figure A.1 and A.2, has shown that the method can be replicated. The map is known to work in VR, but it will need some changes to make the experience smoother when viewing it. Automatic zooming was implemented in this prototype. To make it work better in the final implementation, something like dynamic rendering or a buffer needs to be implemented to make it more usable and improve the overall experience.

### A.3.2 Globe Visualization

In the previous map-based implementation, the images were placed directly on the map. To make the exploration of the images easier and clearer, the system in this study indicated image locations through way points. These are indicators containing partial information about the images in that location. One method is to make the way point shaped like a globe and use it to preview some particular images. One could interact with the globe to inspect the preview [20].

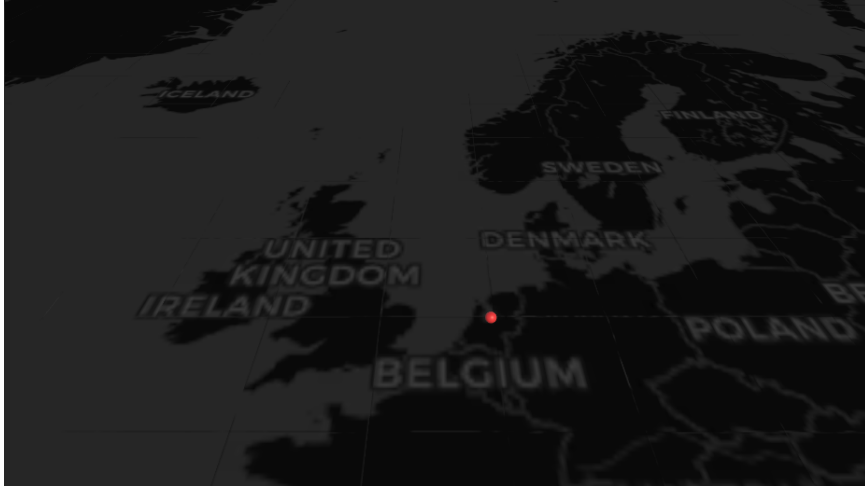


Figure A.2: Early prototype of the map zoomed out.

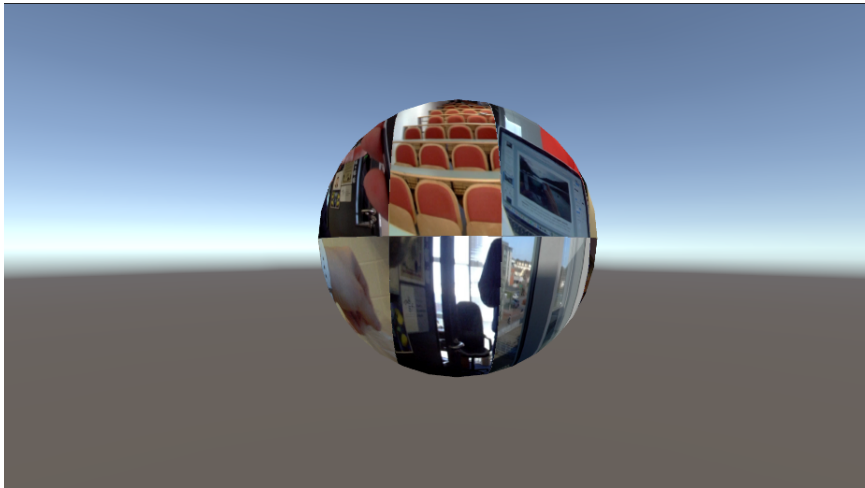


Figure A.3: Early prototype of the globe visualization.

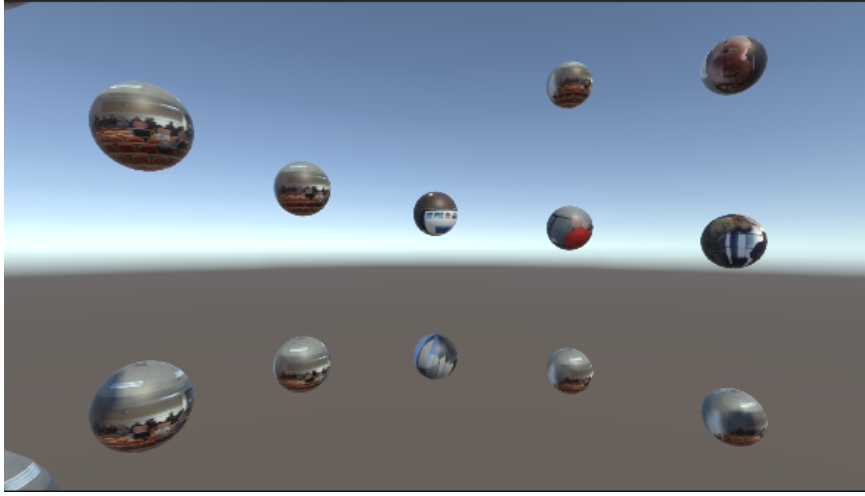


Figure A.4: Early prototype of the timeline visualization.

The prototype, shown in figure A.3, shows that this method might not work for the purpose of this study. The globe is very cluttered and unclear as the distortion of the lifelogging images is enhanced by the distortion of the shape. A lot of changes could improve the method, but it is probably wiser to look at a different visualization method.

### A.3.3 Timeline Visualization

Previous work has shown that trying to place all images on the map has its limits. To explore the data it might be better to preview some images and then let the viewer open up a gallery themselves. Instead of showing a 2D gallery, like the ones used on regular devices, it is more convenient to use the 3D space VR provides. One study [21] has shown the effectiveness of various timeline designs. Lifelogging data has a strong chronological characteristic. This means that it is very likely to be a very intuitive approach to explore the data.

The prototype, as shown in figure A.4, proves the potential of this visualization method. The way it is implemented now, it is possible to manipulate the shape of the spiral in several ways, like angle, height and distance between objects. Testing made it clear there is a lot of design possibility here.

### A.3.4 Film Roll Visualization

Another interesting visualization style to consider is a type of gallery visualization. Here the images are arranged on a cylindrical shape, which the observer can manipulate themselves. This could either be arranged on a vertical roll [22] or a horizontal shape [13]. This visualization is already more commonly used for browsing on VR devices. It also uses the temporal component of the data, but it does not fully use the third dimension. It is nevertheless a potential visualisation method for this study.

## A.4 Memory Storage and Retrieval

Throughout the years many researchers have been studying the concept of a memory machine. A machine which could store and retrieve everything about a person's life. Computer technology came with the ability to store enormous amounts of data. As more and more people start collecting more and more data, a new problem arises, which is, how can people navigate this data. Lifelogging is also a way to digitize personal data, resulting in a large database. This makes it useful to look at other older technologies tackling a similar problem, as it could give us more insights on how to tackle this in the lifelogging system. The latest works are also discussed to see what research opportunities arose from these studies.

### A.4.1 Shoebox

Shoebox [23] was designed in the year 2000, during the rise of digital photography. The researchers believed a tool was needed to manage a large collection of photographs, as personal collections kept growing. The photos would be collected in the program and people could explore the dataset using three browsing indexes, annotations, timeline view and content-based view.

From the surface this is already very similar to the problem tackled in this study. From the research some insight do arise. First of all, it is said that user-interface is important and should be designed with speed, flexibility and visual appeal in mind. This should also apply to the design of the lifelogging system. Secondly, the authors argue that indexing through metadata outperforms visual based retrieval. For our system this translates to the metadata of the dataset and its importance.

### A.4.2 MyLifeBits

MyLifeBits, designed in 2002 [24], is a system designed to store many different personal documents. This could be anything like images, sounds, documents or videos. The lifelogging system will only support image storage, but the design principles are similar for both systems. The most important take away from their design is the use of links. It is important to make good use of the connections that exist between entries in the database. This was achieved in this study through the connections in the metadata. It could be important that the visualization in VR also makes use of these connections in an intuitive way.

### A.4.3 Geographic Lifelogging Systems

As mentioned before, this work built upon a previous lifelogging system. [19] In this study, recommendations for future work were given. This is thus highly beneficial data for this study. The following items were mentioned as future work and will be applicable in this study:

- The improvement of the map.
- Improve the user interaction
- The addition of a temporal aspect.
- Verifying the applicability of the system and the results

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# Appendix B

## Implementation Design

### B.1 Main

The main application has several features implemented. Each of these features went through several iterations at some point during this project. In this section the thoughts and reasoning of the designs are explained. First the setup of the SQL database is explained. Then the design and features of the map interface is explained. The sections after that will explain the clustering and filtering. Afterwards the design of the timeline and content menu is discussed. A detailed description of the final implementation of each feature is also given.

#### B.1.1 SQL Setup

In this project the image information is retrieved from an SQL database. For simplicity, SQLite is chosen for this database, as Unity can use this to read the database offline from a local file. This is also beneficial if it is desired to run the application as a standalone program.

Using Python scripts, the CSV files from the lifelogging dataset were converted to SQL databases. The first version of the database was formed by converting the data in three table, one for the metadata, one for the visual concepts and a separate table for the tags per image. To make the information retrieval in the application simpler and faster, it was decided to combine the visual concepts and tag table into one table from where the image content could easily be found. Table B.1 and table B.2 show how the final version of the SQL database is set-up.

#### B.1.2 Map Design

The idea of using a geographical representation was presented in previous work. This project implemented this again with some new features. During development it became clear that loading the entire map would cost too much resources. This is why only a select area around the user is loaded at once. In the final version this is set to a certain region, that forms the horizon for the user. The

ImageID	minute_id	utc_time	local_time	latitude	longitude	semantic_name
20190101_105421_000.jpg	20190101_1054	2019-01-01 10:54:42	2019-01-01 10:54:42	53.39007141	-6.14566047	Dublin, Ireland
20190101_105453_000.jpg	20190101_1054	2019-01-01 10:54:42	2019-01-01 10:54:42	53.39007141	-6.14566047	Dublin, Ireland
20190101_105922_000.jpg	20190101_1059	2019-01-01 10:59:44	2019-01-01 10:59:44	53.3899548	-6.1456888	Dublin, Ireland

Table B.1: The Metadata table.

ImageID	Tags
20000101_000113_000.jpg	wall,bathroom,indoor,toilet,tile,tiled
20000101_000145_000.jpg	text,wall,indoor

Table B.2: The Visual Concepts table.

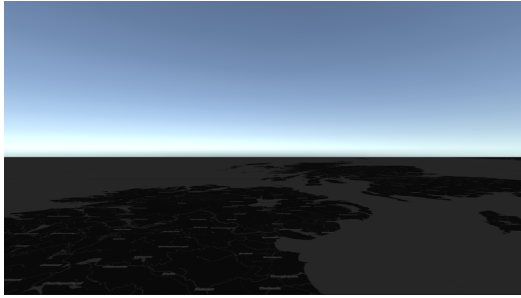


Figure B.1: The edge of the map at low altitudes

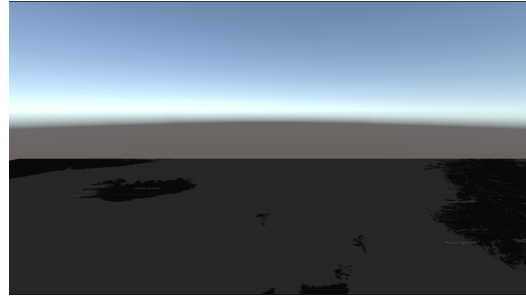


Figure B.2: The edge at a higher altitude

loaded area size also increases when the user moves up, as they are then able to see more of the map. This feature can be seen in figure B.1 and figure B.2. The screenshots show the user at the same but at a different altitude. From the map it can be observed that the border has changed.

The map has another feature, zooming in and zooming out. This is triggered when the users moves closer to the map or further away. When the player moves closer a higher resolution version of the map is loaded. This version also contains more geographical information, such as small town names and smaller roads. When the player moves further away a version of the map is loaded with a lower resolution, also showing less detail. This feature is implemented to create more oversight for map navigation. Several player movement options have been tried in the application. These were joystick movement, flight and teleportation. From these only the last has been scrapped from the final implementation. During pre-testing it showed that this feature wasn't used and it did not work together with flight, which was a more important movement type.

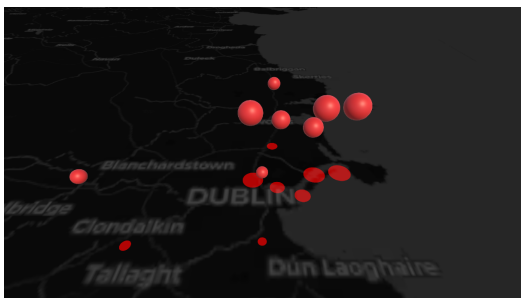


Figure B.3: The map at the lowest zoom level.

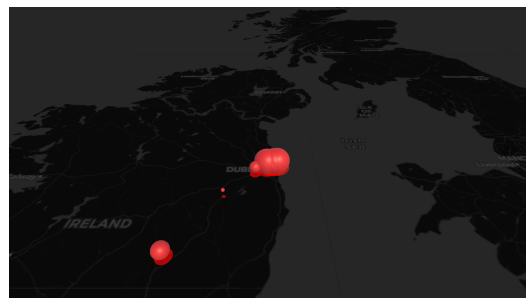


Figure B.4: The map at a higher zoom level.



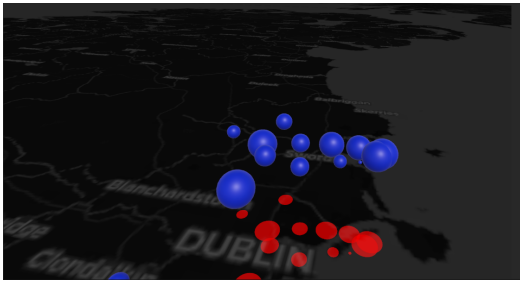


Figure B.5: A cluster set with 15 clusters.



Figure B.6: A cluster set with 25 clusters.



Figure B.7: A cluster set close by.

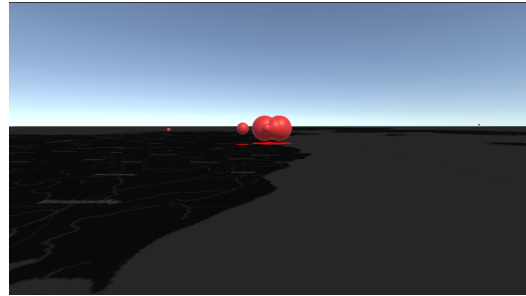


Figure B.8: A cluster set further away.

### B.1.3 Image Clustering

To present the image data more clearly a clustering method was implemented in the VR application. A K-means clustering method is used, based on the locations of the images. This means images are assigned to their closest group. These clusters are then presented on the map, to the user.

In this method several choices were made. Firstly, the amount of clusters had to be determined. Of course more clusters give more information, but it is important to not create too many clusters, as this contradicts the original goal of clustering. Figure B.5 and figure B.6 show a comparison between two different amounts. In the end it was chosen that around 15 clusters would give enough of an overview in the data, while not cluttering too much and still adhering to the main reason for implementing the clustering feature.

Another feature present in the clusters is that they are able to change size. This was implemented as clusters often became very hard to see when the user travels further from the map. It is implemented in a way that their size increases when the user is further away. Even clusters on the horizon become visible this way. Figure B.7 and figure B.8 show an example of this functionality.

### B.1.4 Image Filtering

Another feature of the application is the filtering of images. This is also a feature implemented to increase the visibility of the lifelogging data and increase the usability of the application. Images are filtered by changing the SQL statements. In this way there is never a unnecessary heavy strain by filtering a large set of images. The below SQL statement is an example of how such a code is used.

```
SELECT r.ImageID, l.latitude, l.longitude, l.semantic_name, r.tags
```

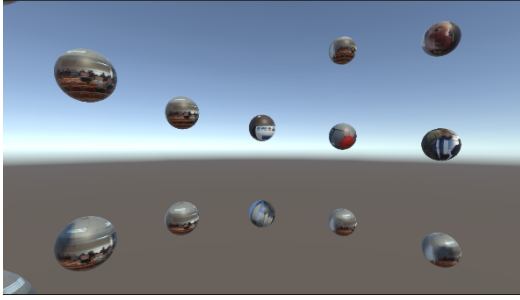


Figure B.9: Early spiral prototype.

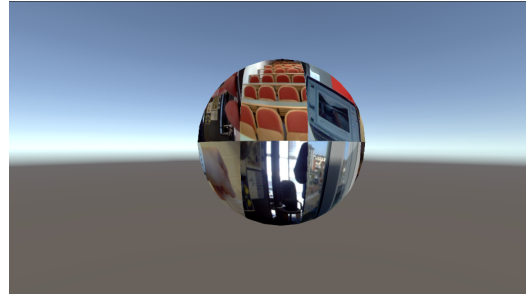


Figure B.10: Early sphere prototype.

```
FROM metadata l INNER JOIN visual_concepts r
ON l.ImageID = r.ImageID
WHERE l.latitude BETWEEN AND
AND l.longitude BETWEEN AND
r.ImageID LIKE OR
tags LIKE
```

This statement consist of three parts. The first is the selection of latitude and longitude. This is based on the dynamic map as explained earlier and makes a first sub set of the images. The second part is the selection on imageID. This is done to select only a certain time frame of the data. In the final implementation, this is used to select images per month. The third component is the filtering through tags. There is also an option not to use this. When used it filters based on selected tags. Multiple tags are combined through an AND connections. This connections works more logically, as more filters decrease the amount of images in the output.

### B.1.5 Timeline Design

To present the image data in a more insightful manner, images are presented in a timeline. Before the timeline was implemented another visualisation was tested. Figure B.10 shows an early prototype of this. In this method, image information is previewed on the cluster indicator. This idea was scrapped as it became clear that this method is too disorderly in VR. Figure B.9 show an implementation of spherical visualisation in the timeline spiral shape. This was an idea early on, but was scrapped in favour of easily viewable flat images. However, these flat images were made to turn to the user, causing a similar effect as was noticed with these spheres.

There are multiple design decisions that were made in the development of the timeline. The most important decision was the spacing of the images. Figures B.11, B.12 and B.13 show a comparison between three options. It shows that the spacing has a large impact on the visualization in the end the second option was chosen as this was seen as the most clear version in VR. It shows the most information without overly obstructing the users' view.

### B.1.6 Content Menu

Filter are applied using a menu. Similar to previous designs, a filtering menu appears when the user presses the corresponding button. Figure B.14 shows the menu. In the bottom menu, the user can select time or tags. In the time section, users choose what months they want to see. The top section



Figure B.11: A timeline containing 30 images per rotation.

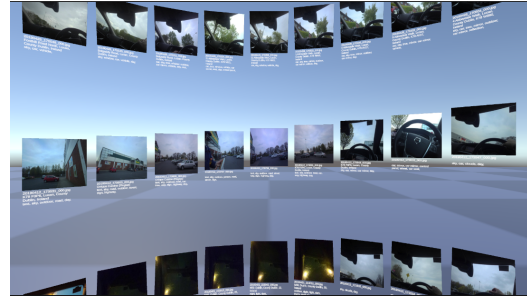


Figure B.12: A timeline containing 36 images per rotation.

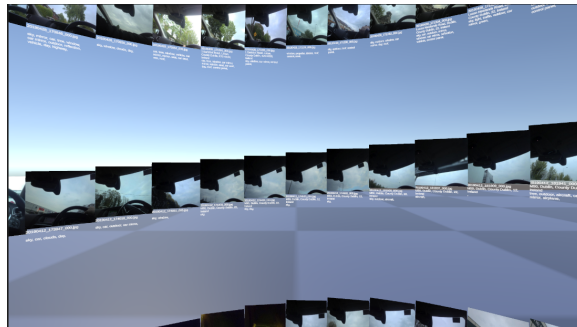


Figure B.13: A timeline containing 43 images per rotation.

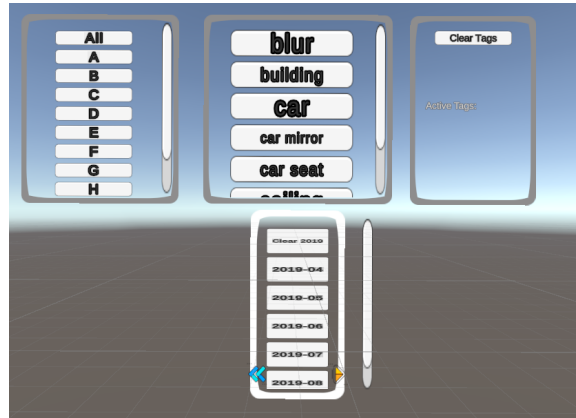


Figure B.14: A cluster set further away.

is for the tag filters. User can select tags with the left and middle buttons and the right menu shows what tags are active.

For the application a selection of tags has been made. The LSC 2023 dataset contains 892 unique tags. Trying to select them all could overwhelm users, on top of this, most tags do not describe a lot of images. This is show in figure B.15. This histogram shows that over 650 tags only describe a few hundred images. This is means it is not very useful to include them in the application. For this reason only the 53 tags are include that describe more than 10% of images. These are 53 tags and cover 95.8% of the image set. Also including the next 50 tags achieves a coverage of 96.7%. With only such a small increase of the set, it doesn't make sense to keep including more tags.

## B.2 Tutorial

Before testing, participants had to do a short tutorial to get familiar with the controls. This had to be done because some participants might have no experience with VR. This would make it very hard for them to use the application for the first time.

The tutorial was set up in four stages. Figure ... shows how these parts are set up in the environment. In each part the participants have the opportunity to get familiar with an important feature of the application. Part 1 explains how the clusters are opened and closed. This is also a chance to learn how grabbing works in general. Part 2 shows a timeline and explains how it can be navigated using the grabbing controls. Part 3 is the opportunity to try the flying controls. For this an object has been placed far away, so the user has to fly up to see it properly. Part 4 shows the user the menu. Here it is important to know what buttons to press and how it works. The design of the tutorial has been chosen this way to keep the focus on learning the controls and not the test. Users get the as much time as they need to complete all parts. Most participants complete this section in a few minutes.

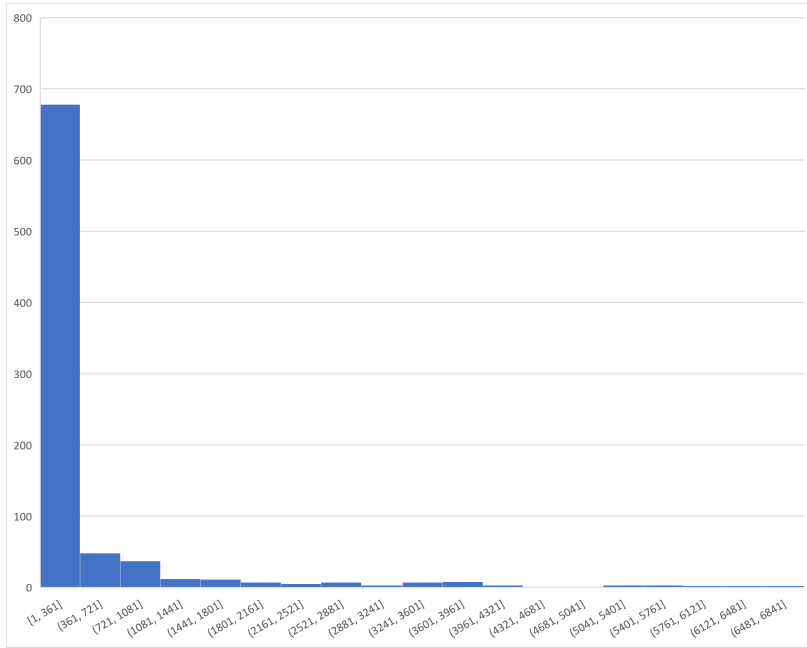


Figure B.15: Distribution of tags with <10% of images.

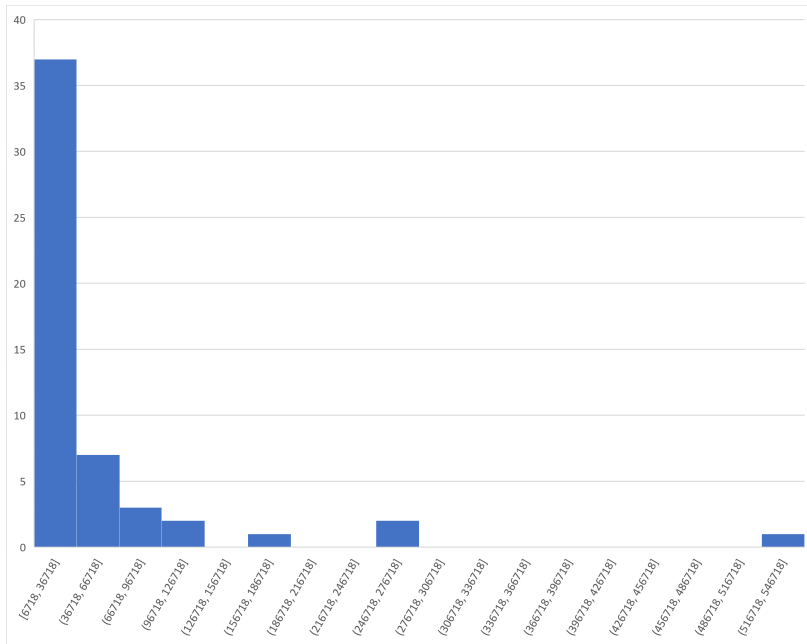


Figure B.16: Distribution of tags with >10% of images.

# Appendix C

## User Study Design

This appendix discusses several parts of the user study.

### C.1 Pre-test

Before the evaluation began a pre-test was performed with 3 participants. From this pre-test several improvements were made. The tutorial section was improved with some additions and one question has been removed from the test.

### C.2 Participants

A detailed description of participants.

### C.3 Evaluation Plan

This document describes the testing and evaluation phase of the project. It contains all the necessary components of the evaluation. In total around 20 participants will test the system. A single test will take around 30-40 minutes. A test comprises of a consent form, a pre-questionnaire, the VR test and a survey.

The actual form used for the consent form, pre-questionnaire and survey are displayed in a separate appendix. A summary of them will be given here.

#### Timing

Set time windows have been determined for the evaluation, these are shown in table ().

Consent Form	1 min
Questionnaire	2 min
VR Test	35 min
Survey	5 min

## Consent Form

A consent form is used in accordance with the regulations of Utrecht University. An ethics approval was granted for this research. The consent form contains explanations on what the rights of the participants are and obtains their approval to use the data.

## Questionnaire

Before the actual test a questionnaire is filled in to get information of the participants experience with similar systems and other relevant information that could influence the participant their performance and usability of the system.

- Age
- Sex
- Eye Deficiencies
- Experience with VR
- Experience with Map Systems
- Experience with Image Browsing Systems

## The Test

In the VR test the participants put on the headset and try to answer 5 questions. This will make them interact with the system. The participants get a timeslot of approx. 30 minutes to do this, so that the test does not take up too much time. This is excluding the time for the tutorial section. The questions are aimed at exploring the dataset and not retrieval. For each question there is a 6 minute time limit. The test starts with a tutorial section where people can get familiar with the controls. The tutorial has several stages with explanations for the most important controls of the application. If a participant has gone through these stages, they will know enough about the system to use it and are ready to do the actual test. Going through the tutorial will take approximately 5 minutes. No data is recorded during this section. In the second part of the test the participant tries to answer the questions as written below. The questions are similar to questions asked in the LSC challenge. They have been worded to be more open-ended, to keep the participant in an exploratory setting. The questions are asked by the test coordinator who is present during the test, so that the participant is not bothered by unnecessary texts in the application, during the test. This is similar to a regular exploration setting.

- In what city does the subject most likely live?
- Can you name a place abroad where the subject has travelled to?
- Can you find pictures where the subject was near the sea?
- Can you find a picture where the subject was having lunch?
- Can you find a picture where the subject is working?

During the test several statistics are tracked and recorded as well. These are only tracked after the tutorial sections is finished.

- Time, total and per question.
- Order of Questions.
- Answers to Questions.
- Total number of actions.
- Recordings of every actions.
- Logs of the player position.

## Survey

A two part survey. This survey will gather the information about the usability of the application. The first part is about the usability of the system and uses the SUS metrics (Brooke, 1996). SUS has become an industry standard, with references in over 1300 articles and publications. The noted benefits of using SUS include that it:

- Is a very easy scale to administer to participants.
- Can be used on small sample sizes with reliable results.
- Is valid – it can effectively differentiate between usable and unusable systems.

The second part questions the participant about the VR experience of the user when using the system. It contains the below questions. I gives the research more context for the single number that comes from the SUS metrics. The first question asks about common side effects that occur in VR and has been taken from a paper by Kim et al. (2018)

- Did you experience any of the following symptoms?
- What did you like about the system and why?
- What did you dislike about the system and why?
- What do you think this system could be used for?
- Did you think it was easy to find the answers?



## Appendix D

# Participant Statistics

This Appendix contains the figures describing the statistics of the participants in the user study.

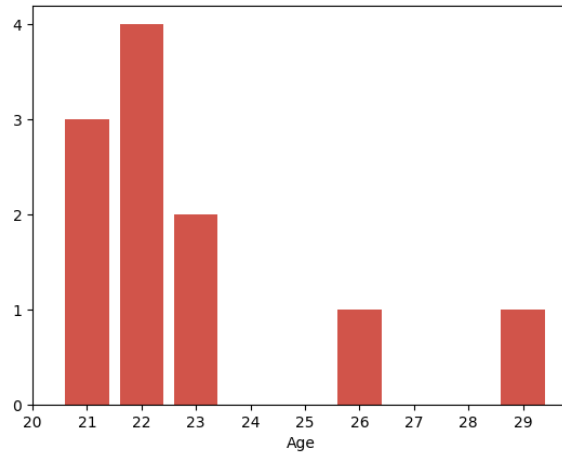


Figure D.1: Age distribution of participants.

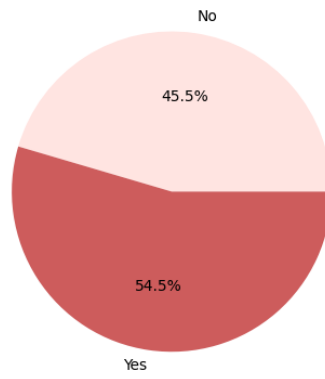


Figure D.2: Participants with eye deficiencies.

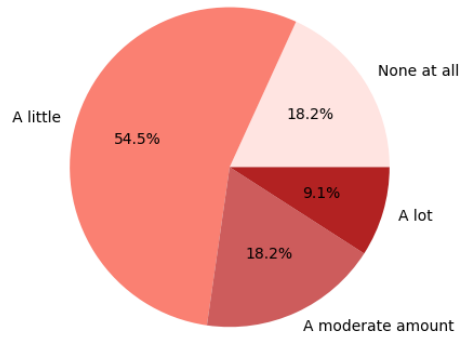


Figure D.3: Experience with VR.

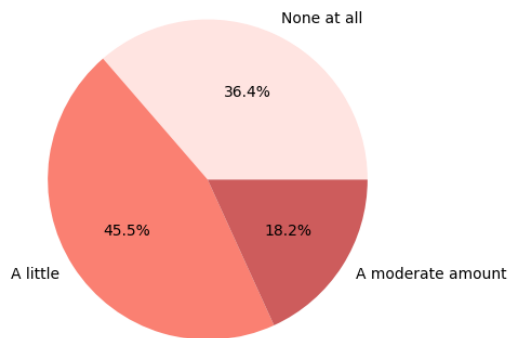


Figure D.4: Experience with Map systems.

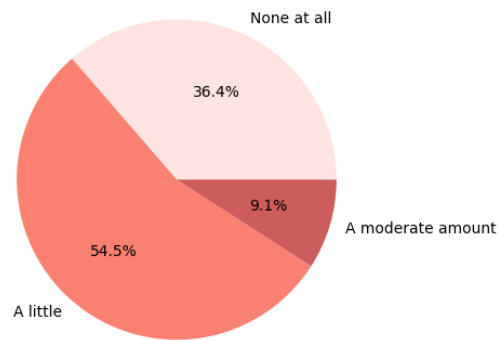


Figure D.5: Experience with Image browsing systems.

# Appendix E

## Survey

### 1. Information Page

The goal of this test is to evaluate a Virtual Reality system that gives you access to photos taken with a body-worn camera. The dataset contains various photos from one person wearing such a camera over the course of various days. When wearing the camera, photos were taken automatically once every minute. We want to see how well our system allows you to explore this dataset.

The test consists of this questionnaire, a test in the virtual reality application and a final survey.

### 2. Consent:

Please read this paragraph before continuing.

We request you to fill in this questionnaire and grant us permission to use the recorded data from your test for research purposes. If you participate in this study, you will give us access to the data you provide in this form. All data will be collected and processed anonymously. No video or audio is recorded in this experiment. The only data gathered is the data you provide in the answers to the questions. The collected data will be stored anonymously and

In this experiment the system is being tested and not you, the participant. Participation in this study is voluntary. If you wish to no longer participate you are free to stop now or later at any moment. You can also take a break or pause whenever necessary. If you experience any form of cyber sickness, e.g. headaches, eye strain, dizziness, etc. please stop the test immediately and let the test coordinator know.

We ask you to participate in this study by answering yes to the below question and agreeing to share the data for research purposes.

For details of our legal basis for using personal data and the rights you have over your data please see the University's privacy information at [www.uu.nl/en/organisation/privacy](http://www.uu.nl/en/organisation/privacy).

3. I agree to participate in this study and agree that my anonymized data can be used for scientific purposes.  
O Yes O No

4. What is your age?

.....

5. What gender do you identify as?

Male  Female  Non-Binary  I prefer not to say

6. Do you suffer from any type of eye deficiency?

Yes  Maybe/Unsure  No

7. How much experience do you have with VR?

None at all  A little  A moderate amount  A lot  A great deal

8. How much experience do you have with map systems (e.g. Google Maps)?

None at all  A little  A moderate amount  A lot  A great deal

9. How much experience with do you have image browsing systems (e.g. Photo Gallery, Instagram)?

None at all  A little  A moderate amount  A lot  A great deal

10. Test

You can now start the test using the VR headset. The test supervisor will assist you. After entering the VR application, the test supervisor will guide you through a short tutorial, after which you will navigate the dataset and try to answer 5 questions.

11. Please answer the following statements.

This question presents the SUS matrix as proposed in the paper by Brooke.(1996)

	Strongly Disagree 1	2	3	4	Strongly Agree 5
I think that I would like to use this system frequently					
I found the system unnecessarily complex					
I thought the system was easy to use					
I think that I would need the support of a technical person to be able to use this system					
I found the various functions in this system were well integrated					
I thought there was too much inconsistency in this system					
I would imagine that most people would learn to use this system very quickly					
I found the system very cumbersome to use					
I felt very confident using the system					
I needed to learn a lot of things before I could get going with this system					

12. Did you experience any of the following symptoms? (Yes/No)

- General Disc
- General discomfort
- Fatigue
- Headache
- Eyestrain
- Difficulty focusing
- Increased Salivation
- Sweating
- Nausea
- Difficulty concentrating
- Fullness of head
- Blurred Vision

- Dizzy (eyes open)
- Dizzy (eyes closed)
- Vertigo
- Stomach Awareness
- Burping

13. What did you like about the system and why?

.....  
.....  
.....

14. What did you dislike about the system and why?

.....  
.....  
.....

15. What do you think this system could be used for?

.....  
.....  
.....