Exploring Collaboration for Data Analysis in Augmented Reality for Multiple Devices

Category: Research

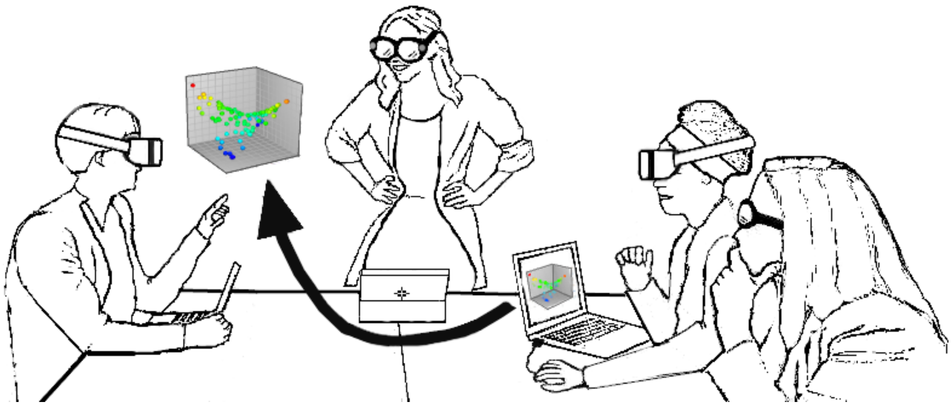

Figure 1: Collaborative setup allowing participants to enhance their notebooks using OST and VST augmented reality devices for data analysis.

Abstract

Collaboration is a key aspect of Cross-Virtuality Analytics. When collaborating in Augmented Reality, there are different types of display technologies available. In this work we elaborate on differences between video see-through, optical see-through and handheld Augmented Reality technologies with currently available hardware. We then present the concept of a prototype for collaborative data analysis combining these different technologies with laptops and pen and paper. Finally, we report on the initial findings of a pilot study on the impact of these technologies on collaboration in data analysis.

Index Terms: Human-centered computing—Mixed / augmented reality; Human-centered computing—User studies;

1 Introduction

In the fields of cross-reality and the closely related cross-virtuality analytics [21], Milgram's Reality-Virtuality Continuum (RVC) [17] is a common frame of reference. It describes the space between reality and virtuality and locates augmented reality (AR) closer to reality and augmented virtuality (AV) closer towards virtuality. However, within the area of AR, there are different technological possibilities that can be located on different stages of the RVC, see Figure 2.

In this work we want to gain initial insights into the differences in collaboration and data analysis in AR that is caused by the different technologies of the AR devices. To achieve this goal we created a prototype that allows for three users to collaboratively perform visual data analysis in AR while each of them is provided with a different type of AR device. We look at video see-through (VST) AR using a Varjo-XR3 Head-Mounted Display (HMD), optical see-through (OST) AR with a Magic Leap One HMD and Tablet AR using a Samsung Galaxy Tab7. Additionally, each collaborator is provided with pen and paper for taking notes, as well as a Laptop to configure the data visualisation according to their needs. We chose to integrate these Laptops to provide all users with the same mode of interaction for data configuration, as we wanted to focus on the difference in device technology as opposed to the modality of interaction. We performed a pilot study with 2 groups of three participants answering questions by visual data analysis of a data set on cars. Each of the participants worked with each of the devices and answered questionnaires on simulator sickness, task load and user experience. Additionally, they took part in a semi-structured group interview on their experience with the devices and the influence on their collaboration in the task.

2 Related Work

To clarify what aspects and configurations of collaboration in AR have already been explored, we shortly review the field of collaborative collocated AR. Furthermore, we consider Immersive Analytics (IA) [4] to be highly related as it provides the use case, as well as the structure for the pilot study.

2.1 Collaborative AR

Over the years there has been a considerable amount of research in collaborative AR. In their survey, Sereno et al. [23] review collaborative Work in Augmented reality along the categories of Johansen's Time-Space Matrix [10], but also include input and output devices as well as the dimensions of role symmetry and technology symmetry in the collaborative setting. For our current work collocated AR collaboration with multiple devices and asymmetric technology configurations using different AR devices are the most relevant.

For the area of asymmetric technology with different types of AR devices, MacWilliams et al. combine an AR-HMD with a handheld AR device as well as a Laptop and projection-based AR in a game for herding sheep [16]. This project is meant to demonstrate and test the abilities of combining differnt devices with tangible interaction. It mostly focuses on the technical implementation and includes informal user feedback, but does not investigate the differences in devices and collaboration.

In terms of collocated collaboration, there are numerous publications ranging from handheld AR sports [9, 18], over research on collaborative interaction with a virtual object using handheld AR devices [19, 20], towards combinations of AR HMDs with touch devices and handheld displays [1, 13, 23].

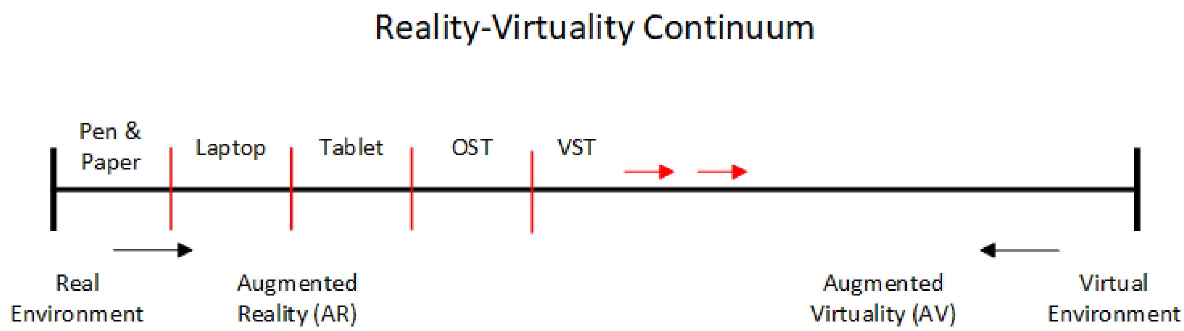

Figure 2: Sketch of AR-devices on the RVC, adapted from [17].

2.2 Collaboration in Immersive Analytics

The term Collaborative Immersive Analytics has been introduced by Billinghurst et al. as: "*The shared use of immersive interaction and display technologies by more than one person for supporting collaborative analytical reasoning and decision making.*" [2]. The availability of relatively low cost HMDs not only enable broader research in and use of collaborative immersive data analysis without requiring CAVE-style environments, HMDs are also able to outperform CAVE-style environments in terms of task completion time [6]. While this study focuses on pairs of collaborators, HMDs can also be used for collocated collaborative data analysis of more than two people [15].

Using AR instead of VR for displaying three dimensional content in a collaborative data analysis scenario, it enables the combination with other 2D technologies, such as a large wall screen for displaying a shared two dimensional view where the AR view is used as a personal view [19]. Moreover, the AR HMD can also be used to establish a shared view that can be manipulated using either one large shared touch device [3] or several small personal devices [23]. Another option is to establish a shared view that effectively combines several tablets and AR HMDs to combat spatial limitations of the small displays [13]. While the above mentioned collaboration utilised off-the shelf touch interfaces, there has also been research into custom clear tablets that are tracked in space which enable interaction in AR without obstructing the view [12].

3 Concept and Design

While the RVC is popular, the other three dimensions of this taxonomy for mixing real and virtual worlds are less commonly used. This concept revolves around the Extent of World Knowledge (EWK), the Reproduction Fidelity (RF) and the Extent of Presence Metaphor (EPM) [17].

- EWK describes how much is known about the environment and its objects. On the lower boundary of this continuum we find for example the real environment seen through an OST device or a VST device. The system has no information on this environment and the contained objects and only provides a reflection, without processing the image to gather information. When looking at the other end of the EWK dimension, the system has all information about each aspect of the objects and the displayed environment as it is found in completely virtual environments.

- RF refers to the quality of the reproduction of both digital and real content. Therefore, an OST display has a high RF in terms of real environments, but a relatively low RF in terms of digital content. A VST display on the other hand, provides high quality images of the digital data while lacking behind in reproducing the real environment. While tablet based AR is also able to reproduce digital content in a high quality, it only provides a monoscopic video of the real environment.

- The EPM dimension refers to the intent of feeling present in the displayed scene. EPM is assesed based on technical ability, such as monoscopy, stereoscopy and real time imaging. Therefore it is more closely related to the concept of immersion, which describes a systems ability to support sensorimotor contingencies, than place illusion, which refers to a feeling of being in an environment despite knowing that you are not [24].

Based on Milgram's taxonomy there clearly are differences in the device types. For OST and VST devices, these differences have also been addressed by Rolland et al. [22].

Properties	VST HMD	OST HMD	Tablet
Stereoscopy	+	+	-
Field of View	+	-	∼
Contrast	+	-	+
World Resolution	∼	+	∼
Latency	∼	+	∼
Free Hands	+	+	-
Social Acceptance	-	∼	+
Safety	-	+	+

Table 1: Summary of the properties of different types of AR devices. The symbols describe whether the respective category is well (+), moderately (∼) or insufficiently (-) fulfilled by the device type.

We condensed the aspects of their comparison that are most important to our current work into Table 1. Moreover, we updated the interpretation to fit the hardware that is currently available and added the Tablet based on our own experience. We also added the stereoscopy and free hands property, as they are especially relevant in the comparison with the tablet. The property of contrast relates to the dimension of qualitative aspects and world resolution relates to real-scene resolution in the work of Rolland et al. [22].

With these differences in devices, we now want to explore, whether they make a difference in behaviour and collaboration when combined in a collaborative scenario. The pilot study described in this work, is conducted to gain first insights into these questions where different types of hardware, represented by the specific hardware listed in Table 2, is applied to the same task in the same collaborative setting.

4 Prototype

Figure 3 shows the structure of the prototype to realise the collaborative cooperation between the devices, it consists of a server and six

Device	Device Type	Horizontal FOV	Resolution	Tracking	Input
Varjo XR-3	Video see-through HMD	115°	Focus area: 1920×1920 per eye Peripheral area: 2880×2720 per eye	Basestations + Marker Tracking	Controller
Magic Leap One	Optical see-through HMD	40°	1280×960 per-eye	Marker Tracking	Controller
Samsung Galaxy Tab 7	Tablet	based on distance	2560×1600	Marker Tracking	Touch

Table 2: Summary of the AR hardware used in the pilot study.

clients. The six clients consists of three different AR device clients these are a tablet, an OST HMD and a VST HMD. Each of these devices is enhanced with a notebook client. The specific hardware used in the study can be seen Table 2.

Unity (2020.3.48f) was used to develop the prototype as it supports multiple operating systems. A client-server approach was chosen to connect the different devices.The network connection was established by implementing Unity Netcode[1]. Since Unity Netcode supports messages via remote procedure calls, these were used for communication between server and client. The command pattern was implemented on the server and client side in order to execute the commands for the changes of data visualisation.

The immersive analytic toolkit (IATK) from Cordeil et al. [5] was used as a basis for the 3D-scatterplot visualisation of the data and was adapted for our application. For positioning the data plot correctly in the room, the Samsung Galaxy Tab S7 and the Magic Leap One uses the ARCore Library [2]. The library allows to track a fiducial marker as shown in Figure 3 and to position the plot based on the marker position. If the marker is not in the field of view, the position is determined by inertial tracking. The Varjo-XR3 uses the Varjo marker plugin for fiducial marker tracking. The marker tracking is applied to obtain the initial reference position of the scatterplot, after that the tracking is handled by the lighthouses. The lighthouse tracking also determines the position of the controller. The position and rotation of the plot is globally aligned the same for all participants. The notebook client has to be used for adjusting the values for the visualisation.

For selecting a specific data point, the Magic Leap and Varjo-XR3 has a controller with which the points can be selected. With the tablet, this is realised via touch input. The selected data is then displayed via a billboard in AR.

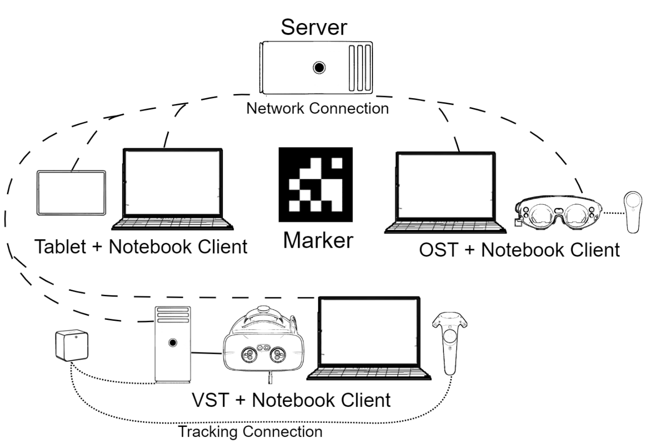

Figure 3: The client-server based architecture of the collaborative prototype for data visualisation.

[1]https://unity.com/products/netcode

[2]https://developers.google.com/ar?hl=en

5 Pilot Study

We conducted a pilot study to see whether there was a difference in user experience, task load and simulator sickness for the three different devices.

5.1 Participants

Six users participated in the pilot study which were split into two groups. The first group consisted of two male and one female participant, the second group consisted of two female and one male participant. The average age of participants was 35 (SD = 4.43). All participants had normal or corrected to normal eyesight. Due to the limitations of the Magic Leap, eyesight could only be corrected using contact lenses, as glasses would not fit under the device. Three participants had a high experience level in visual data analysis, two had medium experience and one had low experience. Two had high experience in tablet based AR, one had medium experience and three had little to no experience. For OST AR one participant was highly experienced, three had medium experience and two had no experience with this technology at all. For VST AR two participants were highly experienced, three had medium experience and one had little experience. Finally, two participants were highly experienced with VR, three had medium experience and one had little experience. All participants were researchers in an IT related field and had a university degree. As the Magic Leap states that it only works correctly when the interpupillary distance (IPD) is smaller than 65mm, we measured our participants' IPD usign the Varjo calibration tool. Five of our participants had an IPD smaller than 65mm, ranging from 60.5 to 64.5 mm. Only one participant had an IPD of 71mm. We specifically asked this participant, if they experienced any issues with blurry vision or perspective distortion, which was not the case. All participants in each group knew each other before the study, but had not worked together yet.

5.2 Procedure

First, users gave their informed consent and were introduced to the dataset and the laptop interface. Each user was then randomly assigned to one workstation that included one AR device, one laptop, as well as a writing pad and a pen to take notes. Users were then instructed that they needed to collaboratively answer questions about the dataset and that at least one of them needed to write the answers down at the writing pad. Then we started with a test trial were they could get familiar with the system and the questions they had to answer. As a dataset we used the Auto MPG dataset from the UCI Machine Learning Repository [3]. They had to answer two questions. For the first question, they were given a set of parameters and then asked to find a specific car. For the second question they had to identify a trend between four parameters of the dataset and how the car they found in the first question compared to other cars in the dataset. When at least one of the participants had written down an answer, the group was asked whether they were done and happy with their answer. Then they were asked to put their AR devices aside and answer a simulator sickness questionnaire (SSQ) [11] as a baseline

[3]https://archive.ics.uci.edu/dataset/9/auto+mpg

for the actual study trials. Then, participants were asked to start their first recorded trial with the same device they used in the test trial. Again, they collaboratively answered two questions that followed the same system as in the test trial. After they were happy with their answer, they filled out three questionnaires. First, the SSQ, then the NASA task load index [8] in the version without rating scales (rawTLX) [7] and then the User Experience Questionnaire (UEQ) [14]. When everyone had finished the questionnaires, participants were asked to switch seats to the next AR device in a clockwise order. We repeated this process until every participant had completed a trial with each of the different AR devices. Then participants filled out a demographic questionnaire and rank the devices from their favourite to their least favourite device. In the end, we conducted a semi-structured group interview asking about their strategies for answering the questions with the different devices and the influence on their collaboration.

5.3 Results

For the SSQ we used the formulas from the original publication [11] with the added brackets. For the rawTLX we multiplied the scores by five to receive a scale from 0 to 100 and calculated the mean values of the individual scales, according to the original publication [8]. The UEQ-scores ranging from -3 to +3 were also calculated according to the original publication [14]. We refrained from calculating statistical significance for SSQ, rawTLX and UEQ, as the sample with 6 participants within 2 groups is too small to find reliable significant differences.

Nevertheless, the results of the SSQ show the clear trend that the VST device (Total Score M = 29.92; SD = 14.24) causes symptoms of simulator sickness in comparison to OST AR (Total Score M = 8.88; SD = 6.73) and the tablet (Total Score M = 4.68; SD = 3.62), see Figure 4. However, only one participant experienced moderate symptoms in any category. All other scores stem from experiencing slight symptoms. While this is not a generaliseable finding, it should be considered in further evaluation. Moreover, it is also to be expected, that the VST would provide higher sickness scores, as it suffers from lower world resolution and latency and cannot be put away as easily as the tablet.

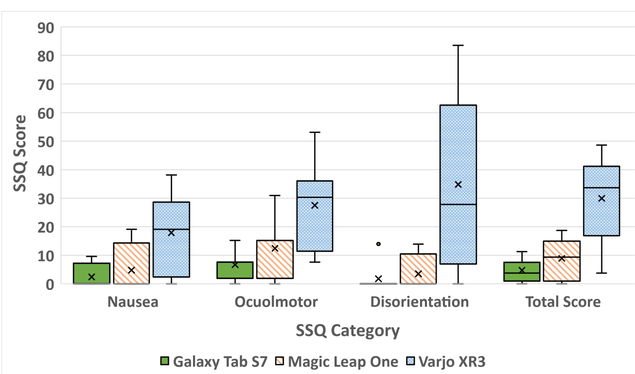

Figure 4: Results from the SSQ.

In terms of user experience, the OST device received the highest average score for Attractiveness (M = 1.06; SD = 0.8) and Dependability (M = 1.19; SD = 0.28). The VST device received the highest average scores for Perspicuity (M = 1.13; SD = 1.22), Efficiency (M = 0.58; SD = 1.25), Stimulation (M = 1.42; SD = 0.75) and Novelty (M = 1.50; SD = 0.8). However for the efficiency scale, none of the devices received an average score higher than 0.8 which would be considered positive. Therefore, all of the devices only received a neutral score for efficiency.

For task load, participants felt that the tablet provided on average a lower mental and physical task load than both HMDs. Additionally, participants felt that on average, they had to put in more effort when using the OST and the VST HMDs compared to the Tablet.

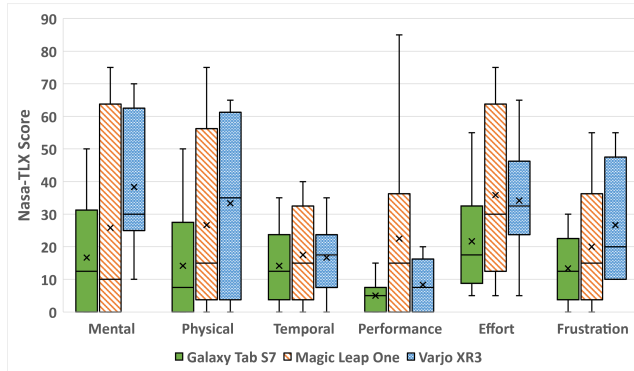

Figure 5: Results from the rawTLX.

These results were also reported in the interviews and throughout the study, were participants felt that the VST device caused discomfort due to its weight. Moreover, participants stated, that it might be worse when being seated during the study as by standing and moving, it would be easier to balance the weight of the headset. For the OST devices, the users mentioned that due to the small FOV, more head movement was necessary. While holding the tablet was heavy as well, it was easier to put it down whenever it got uncomfortable.

Furthermore, participants felt that they were not as engaged in the collaboration when wearing the VST device, as it conveyed the feeling of being more closed off from the other collaborators. However, all users agreed that the VST device with its large FOV and rendering quality of the digital objects was the device best suitable for the analysis in the AR space. The Tablet on the other hand was best suited for taking notes and manipulating the laptop interface.

This is also reflected in the rankings where the tablet is ranked the highest with a median of 1, the VST device received a median rank of 2 and the OST device had a median rank of 2.5.

6 Conclusion

In summary, we reevaluated the differences between different technologies for AR. Furthermore, we presented the concept of a prototype that combines three different device types with a standard laptop and pen and paper in a collaborative visual data analysis scenario. Moreover we report on a pilot study with first insights on the differences in collaboration caused by the different device technologies.

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