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PSA: A Cross-Platform Framework for Situated Analytics in MR and VR

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Figure 1: PSA is an immersive MR/VR framework for experiencing and analyzing recorded conversations and events. We see two participants represented as virtual avatars engaged in a conversation. Their conversation is accessible with rising speech bubbles next to them along with the associated audio. The display screen shows the visualizations generated by the AI agent Articulate+ based on requests made by the participants. An interactive on-demand word cloud can be used to access attributes used in the meeting and reach any point in the conversation when the attribute was uttered. A ray originating from the participant's forehead may be used to understand gaze patterns. (a)Time Slider that enables users to move to any point in time in the conversation. (b) Word Line showing all occurrences of the attribute *uninsured* on the timeline

ABSTRACT

Using immersive environments for training, education, and recreation is becoming increasingly popular among individuals. In recent years these environments have also been used to facilitate data analytics processes involving interaction and task completion. In this work, we discuss Personal Situated Analytics (PSA) a cross-platform framework to embed users into recorded conversations with support for multiple degrees of immersion in the Reality-Virtuality spectrum. Our development pipeline consisted of several stages: tracking, data capturing, data cleaning, data synchronization, prototype building, and deploying the final product to end-user hardware. We evaluate PSA by analyzing data from a recorded meeting involving human participants and a visual conversational AI agent. Our pilot study (n = 12) using this framework compares user experiences for MR and VR environments.

Index Terms: Immersive Analytics—Situated Analytics—Visualization techniques—Human-centered computing;

1 INTRODUCTION

Situated Analytics is an emerging concept in HCI that has gained interest from multiple research communities, including visualization, human-computer interaction, and augmented reality. Situated Analytics recognizes the importance of data analysis within its physical and temporal contexts in which it occurs for meaningful insights and understanding. Studies have demonstrated that when users engage with data in immersive environments using head-mounted displays, they can experience a greater level of presence and immersion, leading to improved cognitive processing and decision-making. In our work, we exploit these ideas in order to provide users with the ability to experience and analyze recorded conversations in situ using head-mounted displays. The information in the conversation is presented as an audio/visual experience. The transcribed speech is visualized through gradually rising bubbles of conversation snippets. These conversation snippets are placed next to their respective avatars, representing real people in the conversation, and all objects and media are displayed in the same place as the original meeting. Additionally, we also have the ability to change our viewpoint by moving around in space and getting close to objects of interest. Figure 1 gives an overview of the application and its features.

Situated Analytics thus far has mostly been explored in the Augmented/Mixed Reality setting thereby providing the users the spatial context necessary for their exploration. Their lack thereof in virtual environments is due to most virtual reality headsets and devices being non-see-through in nature thereby obscuring the spatial context. Hence we use a 3D model replica of the room where the conversa-

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tion occurred to simulate the environment in Virtual Reality. We then measure differences in the users' experiences in both Mixed and Virtual immersive environments.

2 RELATED WORK

2.1 Immersive Analytics

Immersive Analytics combines paradigms from multiple fields such as virtual and augmented reality, data visualization, visual analytics, computer graphics, and human-computer interaction to enable users to interact with and gain insights from complex data in immersive and interactive environments. The technologies used for immersive displays come in various forms such as room-sized CAVE-like projections [4, 10], Virtual reality Head Mounted Displays (for eg: HTC Vive, Meta Quest) [5], interactive tables, walls, multi-display environments [28] and portable Augmented Reality head-mounted displays such as HoloLens and ARGlasses.

Research has shown that understanding data visualizations through immersive analytics can be significantly more effective when compared to traditional interfaces. Sawyer et al. demonstrated that collocated collaboration can provide significant benefits by showing through their experiments that team rooms supporting face-to-face activities helped focus the activities of work groups and isolated them from interruptions [24]. In a similar work, Teasley et al. showed that "war rooms" with access to tools such as computers, whiteboards, and flip charts were twice as productive as similar teams working in a traditional office environment [27]. In their review of three Immersive Analytics projects undertaken by research teams using the CAVE2 immersive projection environment Marai et al. found significant benefits from teams working together in an Immersive Analytics setting [16, 17]. These studies inform us how immersive analytics proves to be a valuable tool for analytical tasks, as opposed to conventional interfaces.

2.2 Situated Analytics

Significant advancements have been made in the field of situated analytics, which has facilitated researchers and analysts in gaining a better understanding, and decision-making based on complex data representations. Real-time exploration and analysis of data in the user's physical environment have been made possible through situated analytics [6–8]. It can be used to create AR and VR authoring tools that leverage information from reality to assist non-experts in addressing relationships between data and pertinent objects [3, 18, 22]. Researchers have also explored how in situ analysis may be used for visual search tasks, information retrieval, and exploration and manipulation tasks for information visualized in its semantic and spatial context [1, 2, 15, 31]. Mapping data on 3d spatial terrains to provide insight into data through immersive interactive applications using head-mounted displays has also gained interest [19, 32].

Situated analytics has also been used for a wide variety of topics including in situ interactive exploration of mineralogy spatially co-located and embedded with rock surfaces [9], exploring graphs with node-link structures [14] and for storytelling [13]. It has also been used to train students and professionals for the industry [23] and for scientific visualization of volumes using density-based haptic vibration technique and an adaptation of a cutting plane for 3D scatterplot [21]. Multiview (MV) representations along with situated analytics can be used to potentially address complex analytic tasks in immersive visualization [29]. Hubenschmid et al. in their work Relive [12] bridge the gap between in situ and ex situ analysis thereby demonstrating a pipeline for exploration and analysis. These works show how situated analytics can be used to build context-aware applications for exploration, manipulation, training, and navigation in immersive environments. However, they lack the embedding of situated analytics as a part of an analysis pipeline. They also, do not explore the differences in the experiences of users between the MR and VR environments. Our work addresses both these areas thereby adding research insights to this emerging field.

3 METHODS

3.1 Data

We captured live conversations lasting approximately 60 minutes where individuals interact with Articulate+ [25, 26]. Articulate+ is an always-listening AI agent that can disambiguate requests and spontaneously present informative visualizations on an 18-screen tiled display wall. Our data capture includes video, audio, screen usage, and head and body movements of the interacting individuals. For tracking head and body movements, the OptiTrack motion capture system consisting of 24 cameras was used. Markers were attached to the chairs of the participants and an Optitrack hat was used to track head movements. We chose the two most suitable conversation datasets from all our capture sessions to be explored in our study one each for MR and VR sections.

The chosen conversation dataset characteristics:(a)Have an appropriate conversation length to consist of enough data for exploration by users. (b)Have a minimal accent such that it can be easily transcribed by Google speech-to-text API. (c) Be void of discrepancies in tracking information in order to generate seated avatars throughout the conversation.

3.2 Data Transcription

In order to simulate live captioning of the conversation content we decided to have rising speech bubbles close to the avatars representing their speech content [20]. We then used Google speech-to-text API to transcribe data and to get the timestamps of each text blob. Google speech-to-text provides several parameters to customize transcription. We used `en_US` Language parameter and the `latest_long` model parameter for transcription. However, it was noticed that the transcription was not accurate. Hence, through several iterations of manual comparison of the audio, video, and edited transcription, we were able to generate a near-accurate transcription.

3.3 Implementation and Interactions

Fig. 2 shows the workflow employed to develop and deploy PSA to HoloLens2 and Quest2. To develop our MR and VR prototypes, we used the Unity Game Engine [11], which is a cross-platform engine developed by Unity Technologies. For HoloLens2, we used the MRTK SDK and for Meta's Quest 2, we used the VRTK v4 SDK within the Unity game engine.

We developed a prototype for comparing the experiences in Mixed Reality (MR) and Virtual Reality (VR) environments using the HoloLens2 and Quest2 devices, respectively. The prototype offers two modes of interaction to navigate to a different point in time: one with a time-slider and the other with a word cloud. The slider allows users to move to any point of interest in the conversation by dragging the slider button on either side. When a user stops the time-slider button at a particular point on the slider, the conversation, including video, audio, speech bubbles, and head positions, moves to that point in the conversation. On the other hand, when a word of interest is touched, the word lines for each of the avatars get populated with capsule buttons representing all points in time where the words occurred in the conversation. Users can touch these capsule buttons to move the conversation to any occurrence of the word in the conversation.

It is worth noting that users use different interaction modalities based on the device they are using. In the MR version, the users use gesture-based interactions, such as touch gestures to interact with menu buttons, words, and capsules on the word line. The main time slider is controlled using the pinch gesture. In contrast, users in the VR version use controller-based interactions, such as using the controller to touch menu buttons, words, and capsules on the word lines, and grab and drag actions to move the slider button.

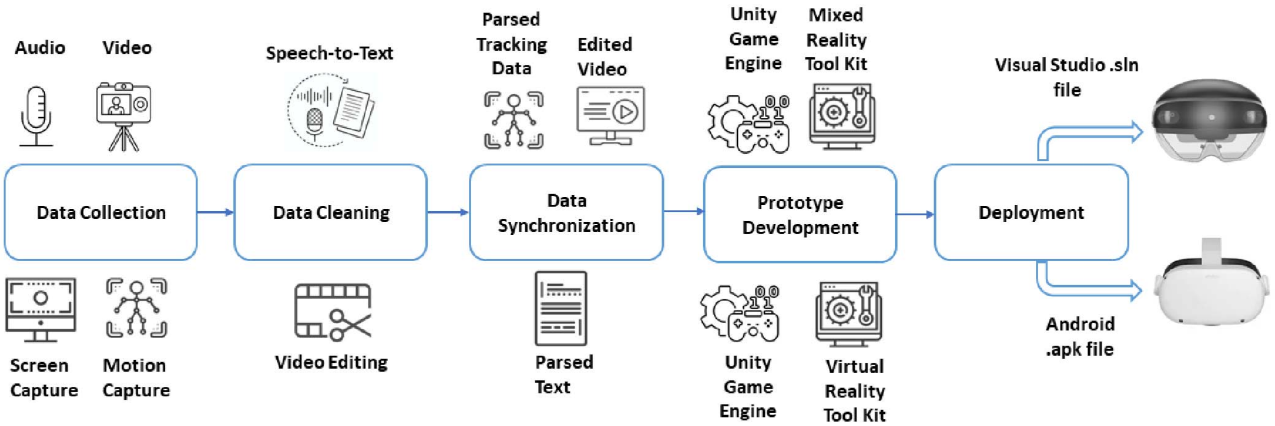
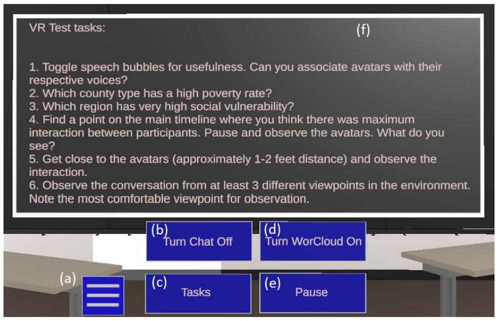


Figure 2: Workflow employed to implement PSA. Our data collection process involves recording Audio, Video, Screen Capture, and Motion Capture. This step is followed by Data Cleaning involving speech-to-text conversion, and manual editing of transcription and video. The next step involves synchronization of all the edited data. Next is the prototype development step in Unity using MRTK (MR) and VRTK v4 (VR) SDKs. The final step involves deploying the software to HoloLens2 and Quest2 devices.



VR Test tasks:

1. Toggle speech bubbles for usefulness. Can you associate avatars with their respective voices?
2. Which county type has a high poverty rate?
3. Which region has very high social vulnerability?
4. Find a point on the main timeline where you think there was maximum interaction between participants. Pause and observe the avatars. What do you see?
5. Get close to the avatars (approximately 1-2 feet distance) and observe the interaction.
6. Observe the conversation from at least 3 different viewpoints in the environment. Note the most comfortable viewpoint for observation.

Figure 3: PSA Menu (a) Main Menu button (b) Turn Chat Off - used to toggle the rising speech bubbles. (c) Tasks - Used to toggle the tasks board. (d) Turn Word Cloud On - Used to toggle word cloud. (e) Pause - Used to toggle between Play and Pause. (f) Displays tasks for the current session.

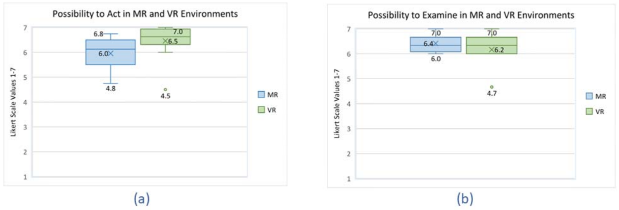
Capabilities: Following is a list of capabilities that PSA offers:(i) Move to any point in time in the recorded conversation (ii)Select important attributes in the conversation through word cloud and move to a specific point in time where a particular word (data attribute) was uttered; (iii) Toggle live speech transcription; (iv) Bring up task list or any information to help navigation; (v) Pause, replay, rewind, and fast forward the conversation; (vi) Ability to move about the room and the data and get closer to an object of interest; (vii) Change viewpoints at any time. Fig. 3 shows a list of tasks in the VR environments along with the menu items.

Figure 4: A user embedded in a conversation using Personal Situated Analytics in Virtual Reality.

4 Pilot User Study

We designed a within-subjects user study where the users used HoloLens2 in one part and Quest2 in the other part. The order of device usage was counterbalanced across participants. Each part was further divided into training and test parts with 10 minutes for training and 15 minutes for the test part. Figure 3(f) shows a list of tasks in the VR version for the test part. The MR test tasks only differed in tasks 2 and 3 which are data-specific tasks in order to mitigate any potential bias stemming from prior experience. The users had the ability to freely interact, explore and analyze a recorded conversation in immersive environments and understand the content of the conversation. The primary objective of the experiment is to understand the efficacy of using situated analytics to experience and analyze recorded conversations. The application provides the ability to navigate in a simulated environment where the objects in space are at the same location as they were in the original conversation. We recruited 12 students from the University's student population which consisted of 5 female and 7 male users between the ages of 20-35. Fig. 4 shows a user immersed in a conversation using PSA.

Space: The study was conducted in a classroom equipped with large display screens, speech recognition, and motion capture systems. The PSA application instantiates avatars representing people in the conversation and provides the ability to navigate in a simulated environment where the objects in space are placed at the same location as they were in the original conversation. In VR, the room has been recreated in Unity but in MR only the avatars, tables, chairs, and the display wall are added to the real room.



(a)

(b)

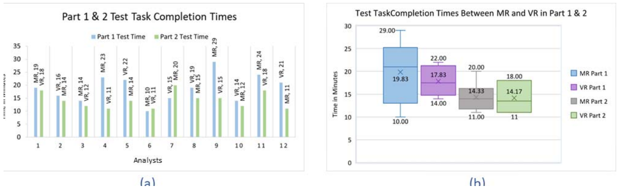
Figure 5: Distribution of means of factors contributing to the Possibility to Act (a) and Possibility to Examine (b) in MR and VR environments rated on a Likert scale of 1 (not at all/not responsive)-7(completely/completely responsive)

5 RESULTS

Overall, all participants reported they were able to learn the gestures and actions required to interact with the applications in both environments during the training parts of the experiment.

5.1 Possibility to Act and Examine

In order to evaluate the usability of the application, we used a subset of questions from the Witmer Singer presence questionnaire [30]. These questions were answered on a Likert scale of 1 (Not at all/Not responsive) to 7 (Completely/Completely Responsive). 4 questions were used to evaluate the possibility to act in the environment i.e. to understand analysts' ability to control the events, act, anticipate, and survey the environment. The average values of all 4 answers for each analyst were recorded. Figure 5 (a) shows the distribution of the Likert scale values of all analysts for the MR and VR environments. Additionally, 3 questions were asked to evaluate the possibility to examine the environment i.e. to understand the analysts' ability to closely inspect objects, concentrate on tasks and change viewpoints at convenience. The average values of all 3 answers for each analyst were recorded. Figure 5 (b) shows the distribution of the Likert scale values of all analysts for the MR and VR environments. Fig. 5 shows the distribution of means of factors contributing to the Possibility to Act (a) and the Possibility to Examine (b) in MR and VR.



(a)

(b)

Figure 6: (a) Test Task Completion times for analysts in part 1 and part 2.(b) Distribution for test task completion times in MR and VR environments in part 1 and part 2

5.2 Task Completion Times

We saw that after the training task, all participants got comfortable with the device usage and interactions with the application. No tasks were skipped. Test task completion times had a mean of 17 minutes (±5.9 s.d.) in MR and a mean of 16 minutes (±3.69 s.d.) in VR. A t-test (two-tailed, two samples with equal variance) showed no significance between the task completion times of the two groups (p-value = 0.59). Figure 6 (a) shows the test task completion times for MR and VR experiences and Figure 6 (b) shows the distribution of test times between Parts 1 and 2.

5.3 Best Viewpoint

One of the tasks involved users looking at the space from different viewpoints in both MR and VR environments. The task was intended to understand two things: 1) the most comfortable location in space to access the information needed for analysis in both MR and VR environments. 2) How the field of view affected their exploration in both MR and VR environments. Based on the survey responses, it was found that most users in the MR environment preferred to stand behind one of the participants, whereas, in the VR environment, most users preferred to stand at the center back of the room. The reasons behind these preferences were attributed to the difference in the field of view of the devices used in each environment. The HoloLens2 has a smaller field of view (FOV) of 52 degrees which made it necessary for analysts to look around more to gather information from the environment. Therefore, standing behind an avatar at an angle gave them a better view of both participants and the screen. However, the Quest2 had a larger FOV of 89 degrees, which allowed analysts to comfortably stand at the center back of the room and still have a view of both participants, their respective speech bubbles, and the screen. This insight can be helpful in designing future MR and VR environments and selecting appropriate devices based on the intended use case.

5.4 Challenges

Cross-platform development: When we started our prototype development process we first used the MRTK SDK to develop the prototype for HoloLens2. MRTK has easy-to-use prefabricated assets (buttons and sliders) that can be used for development purposes. However, when we wanted to replicate the same features in VR for Quest2 for consistency across platforms, we had to create a lot of the assets and features from scratch. This process was very time-consuming and delayed the development process. Hence, while developing a cross-platform framework it might help to be mindful of the aesthetics we choose in our application development.

Overheating of HoloLens2 Device- When the HoloLens2 device was actively used to run the application for over 30 minutes the device would display a warning message asking to shut down immediately due to overheating of the device. For a few of the studies we had to stop the study, shut down the device, and wait for about 5 minutes before we could restart the device and get back on track. However, it is important to note that we only report the times used to perform the task.

Google Speech-to-Text API - As the transcription generated by Google speech-to-text API was not accurate, we had to manually listen to the audio and correct the transcriptions. Another issue was that some of the text snippets generated by the API were too long to be a part of a single text blob for the rising speech bubbles. Hence, the text and the timestamps also had to be split accordingly. This manual editing of text and timestamps led to a lot of synchronization issues between video and tracking data.

Tracking Data/Representation: To ensure that motion-captured data produces natural-looking poses during simulations and enhances the user experience, it is important to either capture the entire body movement or limit the visualization to the head. Failure to do so may result in unnatural poses during simulations and potentially compromise the user's experience.

Avatars - We use only one human model to represent both participants in the conversation. It was hard to depict participants of different heights with one model. Hence we see some discrepancies between the avatar's head positions when compared to the real data.

6 DISCUSSION & FUTURE WORK

The two devices used during the study HoloLens2 and Quest2 used different kinds of input systems. This created an overhead for the analysts to learn two different input systems. It would help to keep the input systems the same across all devices. To achieve this we could either move to a gesture-based system on Quest2 (HoloLens2 already uses a gesture-based input system) or use a voice-enabled input system.

To recreate the environment in Virtual Reality, we utilized a 3D model of a classroom in our laboratory that was previously developed using Blender and Unity. However, it is important to note that this method may not be easily replicable for other settings. Thus, we suggest exploring other options such as using the structure for motion or 360 videos in the VR environment instead, which may be more feasible for certain scenarios.

The ability to change viewpoints in PSA and move around in space offers an effective way of experiencing recorded conversations and can provide valuable insights into how conversations unfold in different contexts. In conclusion, our research can potentially enhance the efficiency of data analysis pipelines and improve our understanding of complex conversations.

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