CDVVAR: VR/AR Collaborative Data Visualization Tool

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ABSTRACT
The emergence of immersive platforms has opened room for designing more effective data visualization tools. Therefore, we developed CDVVAR, a VR/AR collaborative tool that can visualize any dataset using three different techniques. Our prototype enables users to share graphs and highlight (ping) specific data points across VR or mobile AR platforms. We conducted a within-subject study (12 pairs) to evaluate the effectiveness of our prototype. Each pair was shown graphs and asked to point specific data values in both VR and mobile AR setup. The time to collaboratively answer the questions was recorded along with users’ general feedback.

Index Terms: Human-centered computing—Visualization—Visualization systems and tools; Human-centered computing—Human-Computer-Interaction (HCI)

1 INTRODUCTION AND RELATED WORK
Data visualization is often used to present results to discover patterns and predict trends [3]. Most of the immersive analytics problems require collaborative teamwork [1]. However, collaborative visualizations are relatively under-explored, especially using advanced interface tools [1]. Therefore, related work designed effective data visualization tools using CAVE [1, 2], which require a co-located setup. With the accessibility of commercial head-mounted displays (HMDs), researchers utilized them in designing immersive analytics tools in virtual and augmented reality (e.g. tabletop AR) [4]. However, AR data visualization solutions require (1) co-located setups, and (2) physical AR markers that cause tracking problems [4]. The outbreak of COVID-19 elicited the need for developing remote collaborative solutions. Consequently, we designed “CDVVAR”, a collaborative data visualizer in virtual and augmented reality (VR/AR) to (1) support synchronous remote collaborations, and (2) offer a collaborative cross-platform AR/VR solution that can adequately visualize any data-set (csv file). Our prototype utilized three data visualization techniques, namely bar charts, scatter plots, and pie charts; it offers full immersion through supporting VR data visualization, where users can freely interact with and highlight (ping) several data-points. Moreover, it supports the same features in mobile AR to solve simulator sickness issues associated with HMDs and offer portable low-cost remote collaborative analytics solution. To test the effectiveness of our prototype, we conducted an initial within-subject study (N = 24, 12 pairs) with two conditions (AR, VR). We recorded the time taken to collaboratively answer each question (2 Questions) per round along with users’ feedback. Our results show that users answered the first question in the VR mode significantly faster than they did in the AR mode. Moreover, 58 % of users favored the VR prototype for its ease of use. We envision that our work will aid professionals in collaboratively analyzing their data-sets by providing an affordable portable solution.

2 SYSTEM DESIGN
CDVVAR is a cross-platform collaborative data visualization solution that combines the full immersion of VR headsets with portability of mobile AR to (1) visualize different data-sets and share their graphs, and (2) interact with and ping specific data-points to other users. Users can visualize their data-sets (csv files) using three different visualization mechanisms, scatter plot, bar and pie charts. Moreover, our user interface allows the users to filter the data-set according to their specified criteria. We used Flask as the back-end server and Pandas to process and filter the data-set. Meanwhile, Google’s Firebase services were used to (1) store the data-sets and charts, (2) ping data-points between users, and (3) link the VR and AR applications to one another. Finally, we used HTC Vive headset and controllers in implementing the VR aspect and developed an android AR application that relies on AR Foundation to identify a flat surface to render the chart. When the application starts in either mode, the user is prompted to either draw a new graph and share it, or open an existing chart shared by other users. To draw a new graph, the user selects a data-set from a drop-down menu, then selects a chart type. Afterwards, (s)he is shown a panel where several filtering criteria for the data-points are applicable, select an appropriate step-size for any numeric axis, adjust the scale of the graph, and draw and share it (see Figure 1-A). In case of opening an existing chart, the user is shown a drop down list of the available charts. Charts can be viewed in two modes:

Immersive VR mode the users will be placed inside the charts (see Figure 1-C), where they will be able to move to several data-points, hover over them using the Vive controllers to view their values, and ping a data-point to other users by pressing a button on the controller. The users navigate through the data-points using teleportation in an attempt to provide freedom and ease of movement across the virtual environment (VE).

Mobile AR mode the users will be prompted by a yellow arrow to direct their smartphone to a flat surface to draw that chart on the detected surface. After the chart becomes visible (see Figure 1-B) users can use the navigation panel at the bottom of their screen to navigate and ping several data-points. To interact with the data-points, users move their smartphones so that a red dot, shown on the screen, overlay the data-point. Once the red dot overlays over the data point, users’ can view its value and ping it to other users, using the more info and ping buttons respectively in the navigation panel.

3 EVALUATION AND RESULTS
An exploratory within-subject study was conducted to evaluate the usability and effectiveness of CDVVAR. We had 24 participants, 12 pairs, (18 females and 6 males) that were recruited via personal invitations. Each pair was invited individually and placed in a partitioned room (can hear each other). Afterwards, the session started by explaining the experiment to the participants, and familiarizing them with the application. Thereafter, each pair was shown two graphs and asked one question per graph in each mode, where the order of the modes was randomized. The nature of the questions was to identify the values of specific data-points in order to gauge the usability and effectiveness of our prototype. In each mode, we recorded the
time taken to collaboratively answer each question. At the end of the session, users’ feedback regarding the ease of use, freedom of movement, data visibility, and data-point interaction quality were collected. Figure 2-A shows the time taken to collaboratively answer the two questions in both AR and VR mode. The Kruskal-Wallis Test was used to analyze the time results. The test results show that the time taken to answer the first question in AR ($M = 68.17, SD = 40.2$) was significantly higher than that in VR ($M = 47.83, SD = 46.83$), $H(1) = 3.97, \eta^2 = 0.14, p<0.05$. Similarly, the time taken to answer the first question in AR ($M = 68.17, SD = 40.2$) was significantly higher than that taken to answer the second question in AR ($M = 31.42, SD = 19.75$), $H(1) = 9.36, \eta^2 = 0.38, p<0.05$. However, no significant difference was observed in the time taken to answer: (1) the first and second VR questions, $H(1) = 0.61, \eta^2 = -0.02, p = 0.44$, and (2) the second question in VR mode and AR mode, $H(1) = 2.62, \eta^2 = 0.074, p = 0.11$. This implies that in the AR mode users had difficulties in viewing the data initially, but learned fast how to navigate and pinpoint data-point values. Furthermore, users’ initial feedback (see Figures 2-B and 2-C) are in favor of VR mode with (1) 83% stating that data visibility is better in VR mode, (2) 71% preferred interacting with the data-points using the Vive controller, as they reported difficulty in aiming at data-points in AR (hand stability), (3) 58% favored VR mode for the ease of use.

4 CONCLUSION AND FUTURE WORK

Our initial results show that VR mode is preferred when interacting with, navigating through, and spotting the values of several data points. Although users faced some difficulties initially to pinpoint data points in the AR mode, they were able to answer the second question within a comparable time to that of the VR mode. Therefore, we plan to enhance the data pointing mechanism in our mobile AR application and investigate the performance and data perception of users in AR mode further. We envision that our work can be used (1) to aid non-programmer users to easily view and share their charts, (2) as an educational tool for students at different ages to view and understand data visualization concepts, and (3) as a cross-platform affordable solution for professionals to visualize different data-sets.

REFERENCES