Wirtschaftsinformatik 2022 Proceedings

Track 16: Human Computer Interaction & Digital Assistance Systems

Jan 17th, 12:00 AM

Development and Evaluation of a Collaborative Stock Trading Environment in Virtual Reality

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Development and Evaluation of a Collaborative Stock Trading Environment in Virtual Reality

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Abstract. Due to the proliferation of Virtual Reality (VR) technology, VR is finding new applications in various domains, such as stock trading. Here, traders invest in stocks intending to increase their profit. For this purpose, in conventional stock trading, traders usually make use of 2D applications on desktop or laptop devices. This leads to many drawbacks such as poor visibility due to limited 2D representation, complex interaction due to indirect interaction via mouse and keyboard, or restricted support for collaboration between traders. To overcome these issues, we have developed a novel collaborative, virtual environment for stock trading, which enables stock traders to view financial information and trade stocks with other collaborators. The main results of a usability study indicate that the VR environment, compared to conventional stock trading, shows no significant advantages concerning efficiency and effectiveness, however, we could observe an increased user satisfaction and better collaboration.

Keywords: virtual reality, stock trading, collaboration, usability

1 Introduction

Stock trading allows individuals and professional investors to invest their money into stocks [1]. A stock represents a share of a company and a shareholder usually has the benefit to receive a part of the company's profit, called the dividend [1]. These shares can also be traded at stock markets, making the trading easier by bringing buyers and sellers of stocks together. Individuals and professional investors can use this market to buy stocks at a specific price, hope that the stock price increases, and then sell them again to realize their profit. Stock trading is "stressful", because, especially professional investors, have to quickly make decisions about large sums of money [2]. Additionally, traders have to react fast to market changes, as their trading speed impacts their performance [3]. Thus, they continuously watch different financial information, like a bid and ask price, the stock price development, etc. [3]. Furthermore, they collaborate with other traders to, e.g., discuss trade decisions and use various analysis techniques in the decision-making process which further complicates the collaboration between traders. Mistakes of traders result in a loss of money [3]. Individuals lose their own money, but professional investors could lose the money of their organization or institution they are working for. Such an institution is often a bank or a fund, where multiple people have invested their money, and they then lose money too [4]. Therefore, it is highly crucial that the system they use to watch financial information and trade supports them [3].

17th International Conference on Wirtschaftsinformatik
February 2022, Nürnberg, Germany

Currently, stock traders use 2D workspaces such as TraderFox[1] for stock trading. These often consist of multiple screens, where they watch financial information and buy and sell stocks. Overall, these applications use a 2D graphical user interface and are operated with a mouse and a keyboard. However, these typical workspaces for trading have several issues. First of all, the currently used displays have a fixed position, a limited amount of space, and mostly support 2D information neglecting the possibility to support 3D visualization of complex financial data. Thus, traders are limited in the available space for financial information, as also stated in [5]. As they still need to watch much financial information at once, the result is "information clutter" [6], which means that the different objects on the screen overlap and are restricted to 2D representation. A countermeasure to reduce this effect are virtual desktops [6]. Still, this results in a complex GUI, and traders can not see all information on one screen. Additionally, traders only interact indirectly with objects on the screen by using a mouse and a keyboard. Furthermore, these systems do not support the collaboration of multiple traders [3]. Therefore, traders use traditional ways for collaboration. If they are in the same location, they directly talk to each other and look together at the same trading desk. If they are in remote locations, they use chat systems or the phone to communicate. Thus, they do not see the same financial data and can not discuss it easily in a common environment.

Virtual reality is a promising technology to solve these issues. VR interfaces support the interaction in an immersive computer-generated 3D world and have been used in different application domains such as training [7], prototyping (e.g., [8], [9]), robotics [10], education [11], healthcare [12], or even for collaborative software modeling [13]. In the context of stock trading, VR can reduce "information clutter", as traders can look around in the virtual environment and are not limited to 2D screens with a restricted size, resulting in a better overview of the information [6]. It also allows the displaying of 3D data, and thus enables new possibilities to represent financial data. Additionally, VR allows new interaction methods, resulting in more direct interaction with the system through hand tracking [14]. Furthermore, VR has the potential to encourage better collaboration through the provision of a shared space where traders can view financial information and trade together. Based on the problem description and stated ideas above, the following research questions arise: *RQ1) How should a collaborative VR environment for trading work? RQ2) Is a collaborative VR environment for trading more useful than current 2D solutions in terms of efficiency, effectiveness, user satisfaction, and collaboration support?*

To answer these questions, we have decided to explore an alternative solution for stock trading. Thus, we have implemented a collaborative stock trading environment in VR that enables stock traders to view financial information and trade stocks with other collaborators. As the traders share a common VR environment where each trader is represented based on an avatar, the solution enables a natural interaction based on gestures, movement, etc. and supports collaboration for stock trading. The developed collaborative VR environment was evaluated and compared to conventional 2D-based trading applications concerning the usability criteria efficiency, effectiveness, user satisfaction, and collaboration support.

[1] https://traderfox.com

The rest of the paper is structured as follows. In Section 2, we present related approaches which cover stock trading and VR. In Section 3, we describe the solution overview for our collaborative stock trading environment. Section 4 briefly describes the implementation of our VR-based stock trading environment. In Section 5, we present the usability evaluation and discuss its main results. Finally, Section 6 gives a conclusion and outlook for future work.

2 Related Work

The topics of stock trading and interfaces for supporting collaboration within this domain have been already researched in prior work. In the following, we draw on related approaches which especially focus on VR and collaboration in the context of stock trading.

Marshall [15] describes a VR system that displays financial information. The system allows displaying financial information in 3D. The user is also able to adjust the layout of the financial information. The system is only used to present financial information, and thus does not support trading. Collaboration between different users is not mentioned, and thus the system does not support the collaboration between traders.

Maad et al. [16] present a VR representation of a game where the player is the only trader and sets the bid-ask-spread for a single security. The user uses a 3D virtual mouse to interact with the system. This approach is extended by [17] by switching from VR to AR and introducing full-body interaction. Both approaches display relevant aspects of the game in 3D, and thus they enable to display financial information in 3D. However, both are missing trading, as it is only a game and as the game is only for one player, they also do not support the aspect of collaboration.

Melkomian et al. [18] describe a virtual trading system for multiple traders, where the traders use the open outcry method. Open outcry was the primary method for how pit traders communicated trade orders. In this approach, they use their hands and voice to trade orders, and therefore, they use direct user interaction. The basic idea of this approach is similar to ours, as it allows trading and collaboration of multiple traders on the same virtual reality trading floor. However, they do not support displaying 3D financial information, as they only use a 3D virtual trading floor and do not use 3D diagrams to display financial information. Furthermore, since it is only a patent, it does not include a tool-support or usability evaluation.

Martin [19] describes an approach to present a financial portfolio in VR. The approach uses 2D pictures of the portfolio and thus does not display financial information in 3D. The user interacts by walking through pictures of the portfolio, so it uses direct user interaction. As the approach presents a financial portfolio to multiple users, it is collaborative but does not allow trading. In this approach, they neither present a tool nor conduct a usability study that gives insights into the effectiveness and efficiency.

Rumiński et al. [5] present a system that allows switching between VR and AR. This approach allows traders to adjust the position of the virtual screens to their needs. Additionally, traders can use their hands to directly interact with virtual objects in AR or VR. However, this approach is not focusing on the aspect of collaboration. A similar conceptual solution to our approach is presented by Pasupuleti et al. [20] who describe a multi-user virtual trading tool, where the user is located in a virtual room with trading information. The virtual room can be used together with multiple users. Thus, the approach allows collaboration. The system also allows the user to trade. However, they do not specify precisely how the financial information is displayed, but they state that it can be any graphical representation and can be placed anywhere in the virtual room. As this approach is also a patent, they do not present a working tool and no usability evaluation results are provided.

As a summary, we can conclude that the idea of a collaborative stock trading environment was already coined in previous works. However, the existing approaches do not fully cover a stock trading approach in VR that supports direct and natural interaction as well as collaboration. Furthermore, state-of-the-art approaches in this domain do not provide any usability evaluation results to indicate the potential of VR for collaborative stock trading purposes.

3 Solution Overview

In order to answer *RQ1* and to create a collaborative virtual reality environment for trading that is capable of displaying financial information and supporting traders to buy and sell shares, we have designed an overall solution architecture which is depicted in Fig. 1.

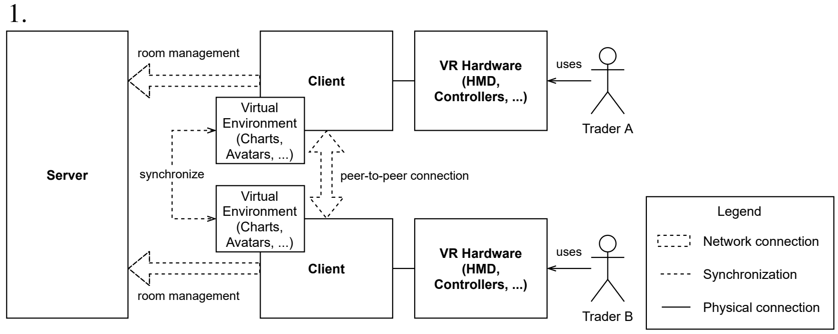


Figure 1. Architectural overview of our VR-based collaborative stock trading environment

It shows that each *Trader* makes use of *VR Hardware* that consists of a *Head-mounted Display (HMD)*, *Controllers*, and other components that depend on the concrete hardware, e.g., tracking stations. The *VR Hardware* is connected to the computer on which the client application runs. It consists of the *Virtual Environment* in which the *Trader* is located. The *Virtual Environment* contains *Charts* and other visualizations, together with an *Avatar* for representing each user. These virtual environments are synchronized between different traders if they are in the same room. This synchronization is done through the *room management* connection to the *Server*, which is used for reliable communication and the management of rooms, e.g., which traders are in which room. The *peer-to-peer connection* between the clients is used for fast updates of the environment and voice communication. The detailed architecture of the client part is presented in Fig. 2 as a component diagram. The *Client* part consists of the components *Collaboration*, *Interaction*, *Visuals*, *Display Output*, *User Interface*, and *Trading Workspace*. Additionally, the services *Financial Data Provider API Wrapper* and *Data Calculation* are included.

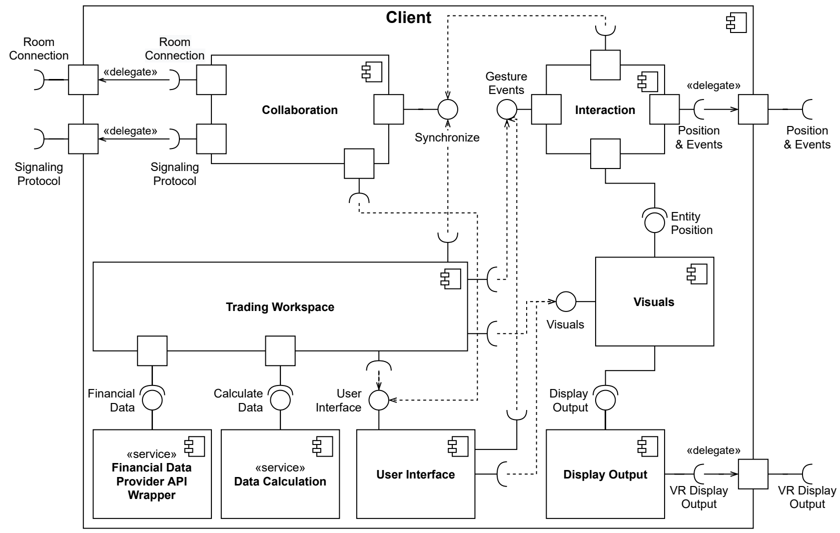


Figure 2. UML component diagram of the *Client* part

The *Visuals* component is used to create virtual objects in a 3D world. It addresses the concept of having geometries and materials that can be combined to create more complex objects. It also provides the ability to place these objects in the 3D world and offers the position information to other components. It uses the *Display Output* component to generate images of the virtual world that can be rendered onto the HMD of the user. Thus, the primary purpose of the *Display Output* component is the rendering of images. The *Interaction* component encapsulates the interaction between the trader and the application. Thus, it directly communicates with the VR hardware to get the position of the controllers and events, e.g., if a button on a controller is clicked. Together with the *Entity Position* of the objects from the *Visuals* component, it can generate gesture events, e.g., if a user grabs an object. Additionally, the *Interaction* component is responsible for the virtual avatar of the user. The *User Interface* component uses the *Visuals* component to generate user interface parts. These parts are, e.g., buttons or input fields. Additionally, it aligns the different parts of the user interface correctly, and it provides a keyboard that the user can use to input text. The *Gesture Events* of the *Interaction* component are used to recognize, e.g., whether a user clicks on a button. Furthermore, the user interface parts are provided to other components, so they can use them to build complex user interfaces. The *Collaboration* component is used to connect to a room and to establish peer-to-peer connections between the clients. These connections are established by using the *Room Connection* and *Signaling Protocol* provided by the server. Additionally, the component uses the *User Interface* component to generate a user interface, which can be used to connect to a room. Furthermore, the *Collaboration* component supports the synchronization of objects between the different users. The *Trading Workspace* component is the main component of the system. It includes domain-specific functions to carry out the trading activities. We decided to split the domain-specific functions into a distinct component to allow the reuse of the rest of the system for other domains.

Through the domain-specific functionalities, it has to use two services. The first one is the *Financial Data Provider API Wrapper*, which is used to wrap the API of a financial data provider, and thus provides *Financial Data* to the component. The second one is the *Data Calculation* service. It is used to process data, e.g., for the scaling of data. Additionally, the service also helps the component to map the financial data to charts.

4 Implementation

In the following, we describe the implementation of our VR-based collaborative trading environment. In this context, we especially focus on the implementation of the *Client*. For realizing the *Client* part of our solution, we have chosen A-Frame[2] as a development framework. In our solution approach, it is used to implement the *Visuals* and *Display Output* components to generate the 3D virtual world and display it on the VR hardware. A-Frame is a web framework, and thus allows to build a VR application that can be run in a web browser. This increases portability and enables a multi-platform VR solution that can be run on different VR HMDs like HTC Vive, Oculus Quest, etc. As a HMD, in our case, we primarily used an HTC Vive Pro[3]. To show that the application can work with multiple headsets, we also used and tested the VR environment on a Valve Index[4]. The used VR HMDs were each connected to a Desktop-PC (CPU: Intel i7 6700K 4x 4.00 GHz, Graphics card: NVIDIA GeForce GTX 1070, 16GB RAM, OS: Windows 10) to run the VR client application. Furthermore, for supporting data visualization in the trading workspace different libraries and technologies have been used. To gather the financial data, we used two different financial data providers. First, because each financial data provider provides slightly different data at different costs. Second, in this way, we can show that the approach can be used with different data providers without problems. We chose Alpha Vantage[5] for historical data and the searching for shares and IEX Cloud[6] for real-time data, as Alpha Vantage does not provide real-time data. For the implementation of the Data Calculation component, we choose D3[7]. It is a library that simplifies bringing data to the web.

In Fig. 3, all three visualization functions that the application supports are shown. On the right side, there is the search. The trader can use it to search for different shares. It uses an input field at the top to allow the trader to input text. When the trader clicks on it, a keyboard will be opened to enter the stock name for which s/he is looking. After hitting the search button, the results are presented. The results show the name of the share and the place where it is traded. Additionally, right next to the name and place, the symbol is shown as a gray box. The trader can grab this box, and then it is possible to drop it onto a socket. Such a socket is, e.g., located on a candlestick chart in the upper left corner. To give the trader a hint that such a box can be grabbed, the box gets thicker if it is selected with the hand or raycaster. After a trader placed the symbol on a socket,

[2] https://aframe.io
[3] https://www.vive.com/de/product/vive-pro/
[4] https://www.valvesoftware.com/de/index/headset
[5] https://www.alphavantage.co
[6] https://iexcloud.io
[7] https://d3js.org/

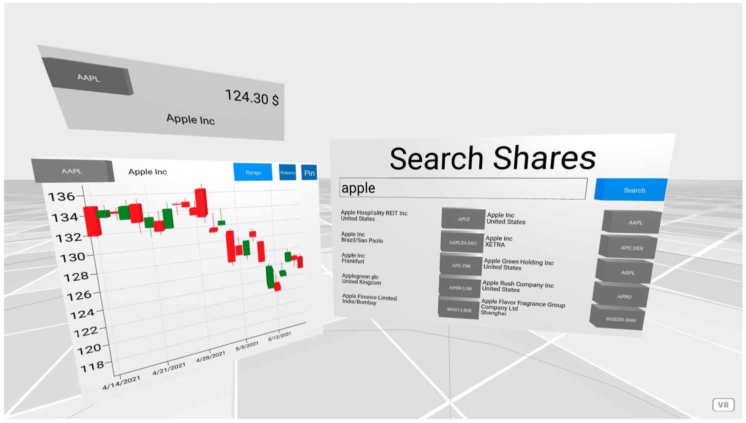


Figure 3. Screenshot of the visualization functions

the associated visualization, e.g., the candlestick chart, will get the stock data. In order to implement the collaboration feature, A-Frame components need to be synchronized, and voice communication must be enabled. For this purpose, our implementation makes use of Networked-Aframe[8] which is a web framework for building multi-user virtual reality experiences. It enables to synchronize A-Frame components between different clients and positional audio. A screenshot from the collaborative VR-based trading environment in action is depicted in Fig. 4. As it can be seen in this figure, the users are represented by a head and hands. Furthermore, it shows that one user points to the chart with the raycaster and uses the pointing gesture. The other user only uses the pointing gesture. It is also shown that the head of a user is visualized including the eyes. This visualization of the eyes makes it possible to see where a user looks and improves collaboration. For example, in the figure, it is visible that both users are looking at the same point on the chart.

5 Evaluation

In order to answer *RQ2* and to evaluate the usability of our collaborative stock trading environment, we have conducted a usability study where we have investigated the usability criteria effectiveness, efficiency, user satisfaction, and collaboration. In the following, the usability study setup and its main results will be described in more detail. Furthermore, a discussion of the results is provided at the end of this section.

5.1 Usability Study Setup

The usability study was conducted with ten participants in total and we had five pairs of participants per usability study session. Each pair had the task to collaboratively work on a scenario in the 2D trading desk TraderFox and our collaborative stock trading

[8] https://github.com/networked-aframe/networked-aframe

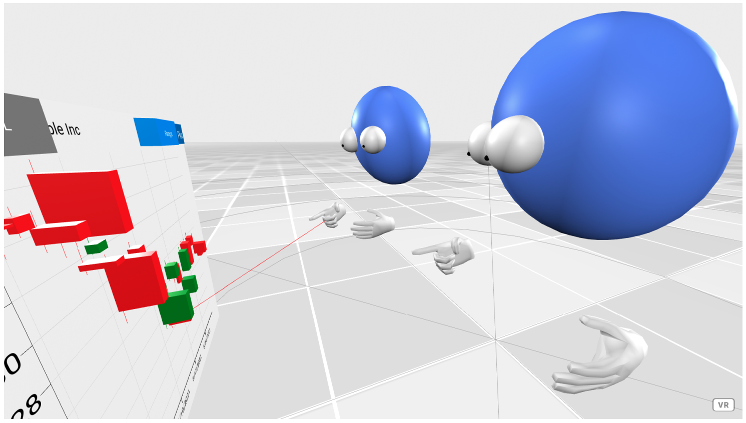


Figure 4. Screenshot of a collaborative trading scenario in VR

environment in VR. Each scenario included a task to compare the price development of different shares, a task to trade shares while comparing data, and a task to calculate the expected gain. These three main tasks of the scenarios helped to compare different features of both applications. The execution of the scenarios on the different applications (2D application vs. VR) was randomized in a way that each scenario was used alternately. The basic setup contained two rooms, A and B. Each of the two participants was in one of the two rooms. Each room contained a PC connected to the internet and via a local network to the PC in the other room. At the beginning of the usability study session, both participants got an introduction to the domain of stock trading. This introduction introduced the general idea of stock trading, candlestick charts, and the two main order types, market order and limit order. This is done to bring participants with no prior experience in stock trading to a level that enables them to understand the scenario. After that, three of the participant groups first did a task in the 2D stock trading application and then in the VR application, and the other two groups first used the VR application and then the 2D application. After the participants used both tools, each of them had to fill out a questionnaire which consisted of questions concerning user satisfaction, interaction, and collaboration. Further details will be explained within the context of the following results.

5.2 Results

The participants reported their experience level in VR with an average of 2.7 and a median of 2.5 (based on a scale from 1-low to 5-high), and their experience level in stock trading with an average of 1.8 and a median of 1. In the following, we describe the main results with regard to the mentioned usability criteria.

User Satisfaction To assess user satisfaction, the System Usability Scale (SUS) [21] questionnaire was used. The average SUS score for the 2D application was 44.0, and the average score for the VR application was 75.5 which is good according to the adjective rating [22]. In addition, the SUS score for the VR application was higher than the score for the 2D application for all participants. We performed a one-sided paired T-test on each participant's score difference to check whether there is a significant difference in scores. We decided to use a T-Test here based on [23], as the SUS score is an interval scale, and the difference in scores was normally distributed based on the Shapiro–Wilks test for normality with a statistic of 0.966 and a p-value of 0.854. Our null hypothesis was that the 2D application has a higher or equal average score than the VR application. The alternative hypothesis was that the VR application has a higher average score than the 2D application. The result was a T-Statistic of 6.228 with a p-value of $7.683 * 10^{-5}$. Thus, with a significance level of $\alpha = 0.1$, the null hypothesis is rejected and the alternative hypothesis is used, indicating a significantly higher score for the VR application.

Efficiency To investigate the efficiency, we measured the task completion time of the participants. To differentiate between the three main aspects of the scenarios, which are the visualization of data, the trading process, and the calculation, there were different checkpoints at which the time was taken. The checkpoints were the following: The first interaction with the form to place an order, after the buy orders are placed, and after the sell orders are placed. Additionally, the total time was calculated. These checkpoints lead to the following five parts for which the time was calculated: *View Data Time*, *Buy Order Time*, *Sell Order Time*, *Calculation Time*, and *Total Time*. The mean time, which the five groups needed for the different parts in each application, is shown in Fig. 5.

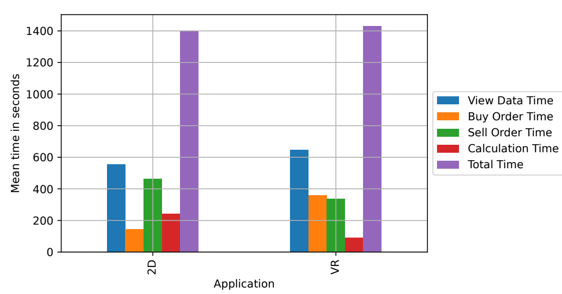


Figure 5. Efficiency results for trading in 2D application vs. VR environment

The total time shows that the groups took slightly more time in the VR application. Two groups were faster in the VR application, and three groups were faster in the 2D application. The Shapiro–Wilks test [23] for normality reported a normal distribution for the differences in total time (statistic 0.945, p-value 0.702), and thus a paired T-Test can be used. We calculated the T-Statistic for the difference between the time they spent in the VR application and the time they spent in the 2D application. The result is 0.162. We then calculated the p-values for two different T-Tests. The first one tests whether the users performed the task significantly faster in the 2D tool, and the second one tests whether the users performed the task equally fast in both tools. The result for the first test was 0.440 and for the second one 0.879. With a significance level of $\alpha = 0.1$, the results are not statistically significant.

Effectiveness To investigate the effectiveness, we used the classification for user errors from Wu et al. [24]. They differentiate between five error types, which are *Misperception*, *Attention failure*, *Perception confusion*, *Memory lapse*, and *Slip*. Every user error was categorized into one of these five error types. We will give short examples for each of the error categories. An example of a *Misperception* is overlooking a data point, e.g., not selecting the highest data point, because the participant did not see it. *Attention failure* is, e.g., trying to interact with a chart without activating the pin, because their attention was already on the chart. *Perception confusion* characterizes errors that result from interpreting the interface of the application wrong, e.g., they click on things that are not clickable. *Memory lapse* happens if the participants forget something, e.g., click on the wrong button on the controller, because they do not know the correct one. *Slip* describes all errors where the participants try to target something and misclick, e.g., they try to pin a chart, but click on the volume button that is directly next to it. The mean errors per group in each application are shown in Fig. 6.

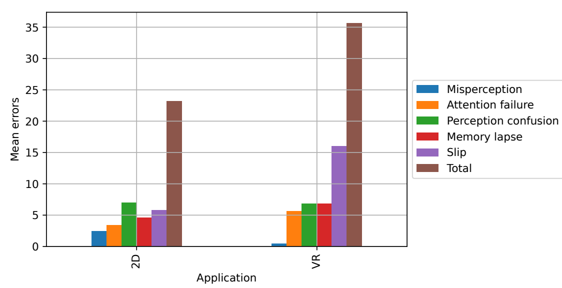
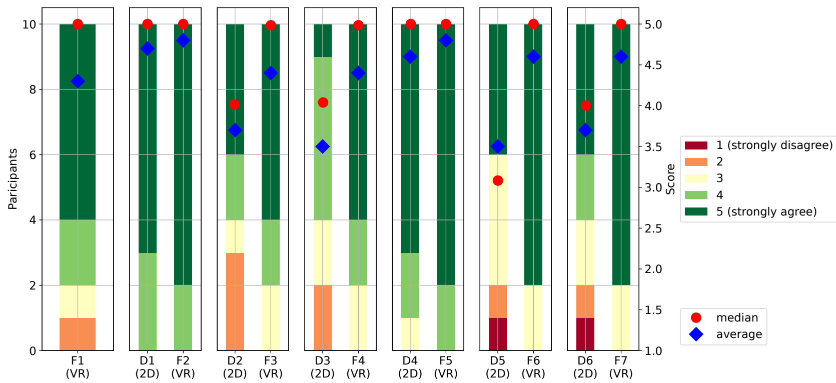


Figure 6. Effectiveness results for trading in 2D application vs. VR environment

In total, the mean number of errors was higher in the VR application. All five groups made more errors in the VR application than in the 2D application. We conducted a one-sided paired T-Test to check whether the total number of errors is significantly higher in the VR application. A paired test, because we compare the same group one time in the 2D application and one time in the VR application. A T-Test, because the number of errors is interval data and according to the Shapiro–Wilks test for normality, the difference in errors was normally distributed (statistic 0.888, p-value 0.346). We used the VR application as the first measurement and the 2D application as the second measurement. The results were a statistic of 2.75 and a p-value of 0.026. Thus, with a significance level of $\alpha = 0.1$, the result is statistically significant.

Collaboration For analyzing the aspect of collaboration, a custom questionnaire was used. It is based on the findings of Tromp et al. [25], who used such a questionnaire for an inspection. Some questions were eliminated, as they do not make sense for this usability study. The items were answered on a 5-point Likert-Scale, ranging from strongly disagree (1) to strongly agree (5), and most of them were asked for both applications. The detailed results of the collaboration part of the questionnaire are depicted in Fig. 7.

Based on these results we can observe that most participants were aware of where the collaboration partner was. We assume that the positional audio helped the users to



Item (Tool)	Question
F1 (VR)	I was aware of where my collaboration partner was.
D1 (2D) F2 (VR)	I could always understand what my collaboration partner was saying.
D2 (2D) F3 (VR)	I was aware of what my collaboration partner was doing.
D3 (2D) F4 (VR)	I always knew what data my collaboration partner was talking about.
D4 (2D) F5 (VR)	I was able to discuss decisions, like the selection of specific shares, the trading quantity, etc., with my collaboration partner.
D5 (2D)	The mouse pointer helped me to show my collaboration partner what I was talking about.
F6 (VR)	The raycaster/gestures/avatar helped me to show my collaboration partner what I was talking about.
D6 (2D)	The mouse pointer helped me to see what my collaboration partner was talking about.
F7 (VR)	The raycaster/gestures/avatar helped me to see what my collaboration partner was talking about.

Figure 7. Collaboration results for trading in 2D application vs. VR environment

know where the collaboration partner was located. Furthermore, the results show that the VR headsets have a good enough sound quality for the collaboration. It was even better than the standard headsets for the two PCs. Additionally, the peer-to-peer connection that transfers the voice had a high enough quality. In addition to that, the users were more aware in the VR application of what the other participant was doing or what data they were talking about, especially the raycaster/gestures/avatar helped them more than the mouse pointer in the 2D application.

5.3 Discussion

Concerning user satisfaction, we could observe that the VR environment was significantly better than the 2D application. This might have different reasons. Firstly, we think that VR technology enables a more natural and interactive experience of the stock trading process. Furthermore, it allows the exploitation of the virtual space in a comfortable way by enabling the visualization of complex diagrams and financial information in an easy way. In addition, many of the participants tried out the VR HMD for the first time and they had a novel and joyful experience of why they might have a positive mindset.

With regard to efficiency, the time measurement showed that the total time is, on average, almost the same, but the results of the T-Test indicate that there is a need for more research with more participants to get significant results. Although the participants reported that it was equally easy or easier to trade in the VR application, the time measurement shows that it was significantly slower if they were only trading. However, if they trade and view the data, they were equally fast in both applications. This indicates that they were faster in comparing data in the VR application to compensate the slower trading process. This is probably a result of the better overview in the VR application. Additionally, as the users reported that the trading process was easier in the VR application, the trading should be less stressful, which improves the efficiency in the sense of the user's workload.

The effectiveness was measured by counting the mistakes. Although the mean total number of mistakes was significantly higher in VR, the categorization showed the details for this. The main reason for the higher mean number of errors in the VR application are errors of the slip category, e.g., not targeting a button correctly. We assume that the users will gain more experience with VR over the years, and thus get used to, e.g., pointing with a raycaster, which will lower this number. The important message that is shown here, is that a VR stock trading application should not rely on single clicks for the trading process, as a user could accidentally click the button. As expected, the mean number of misperceptions is significantly lower in the VR application. It supports the fact, which the users reported, that they have a better overview in the VR application.

Finally, we can observe that collaboration is better supported in the VR application through better awareness of what the partner was doing and using avatars, gestures, and the raycaster instead of the mouse pointer. Thus, we conclude that a collaborative virtual reality workspace for trading can be more useful, especially when traders need to interact and exchange information on a regular basis. However, more research with improved versions of our collaborative virtual reality environment for trading and more participants is needed. As most of the participants in our user study were inexperienced users in stock trading and novice traders behave differently than domain experts [3], it would be especially interesting to evaluate our approach also with more experienced traders.

6 Summary and Future Work

In this work, we have presented a VR-based collaborative stock trading environment. It supports the visualization of financial data in a virtual environment and collaboration between stock traders. Our VR-based solution was compared with a classical 2D-based trading application in terms of the usability criteria efficiency, effectiveness, and user satisfaction. Furthermore, we have analyzed the strengths and weaknesses of our tool concerning collaboration features.

In future work, we plan to extend our collaborative VR trading environment by further features to support the analysis of stocks and intelligent components to better support the decision-making in the trading process. Also, we plan to add further chart types to support an immersive visualization of complex financial data sets. Finally, we plan to conduct a user study with a larger group of heterogeneous users including domain experts to further investigate the benefits of VR for the financial domain.

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