Enhancing Usability in Large Map Interactions: A Novel Magnifying Lenses Technique for Tabletops

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Abstract: Tabletops are large interactive displays that enable users to interact for collaborative analysis and planning on datasets. These devices allow communication using pointing and gestures and interactive zooming, searching, and modifying data. However, when interacting with large maps, the user must analyze details that can only be viewed by enlarging the map region. Furthermore, it is interesting to visualize the context (zoom out) and the details of a specific area (zoom in). Magnifying lenses are often used for this purpose, but these lenses have the disadvantage of losing context. In this paper, we present a new technique for interaction using magnifying lenses for tabletops to improve interaction usability in large maps. We analyzed several techniques discussed in the literature for magnifying lenses. We performed experimental implementations in the context of the SIS-ASTROS GMF Project. We validated the work through objective and subjective analyses, and the results demonstrated significant improvements in objective metrics, such as time and accuracy, as well as in subjective metrics, including frustration, effort, and mental demand. The NASA-TLX Questionnaire was used to evaluate the subjective metrics.

1 INTRODUCTION

The use of interactive surfaces, such as tabletops, has been shown to enhance performance across various tasks (Fitzmaurice and Buxton, 1997) and to be a promising tool in collaboration (Mateescu et al., 2021) and planning scenarios involving large data sets, especially in contexts that require analysis and manipulation of large-scale maps (Döweling et al., 2016). Interactive tabletops facilitate this collaboration by allowing multiple users to interact simultaneously with digital maps, promoting a common understanding of the situation and the improvement of implemented measures (Westendorf et al., 2017).

Tabletops have been used in contexts such as education (Bortolaso et al., 2014), health (Yang et al., 2014; Madni et al., 2016), crisis management (Döweling et al., 2016), traffic simulation (Kubicki et al., 2013), among others. Their use presents satisfactory results with map-related systems due to the panoramic view. In health, the number of elements that can be displayed on the screen allows more details about the medical image to be seen. It supports better analysis (Yang et al., 2014; Madni et al., 2016). Döweling et al. (2016) described the use of tabletops in contexts such as crisis management, in which collaboration between different organizations is essential for situational analysis and action planning. Furthermore, these devices offer an intuitive interface that improves the efficiency and quality of teamwork, overcoming the limitations of traditional

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workstation-based solutions (Döweling et al., 2016; Salvador-Herranz et al., 2016).

Despite the advantages, implementing interactive tabletops presents several challenges. One of the main ones is the need for visualization techniques that allow users to switch between high-level and planned views of the map without compromising collaboration (Bortolaso et al., 2014; Liu et al., 2023; Forlines and Shen, 2005). In large datasets, highlighting a part of the information is a widespread operation. However, contextual data (the area surrounding the interest area) is usually lost when this operation involves zooming. This loss can compromise the user's analysis and, according to Forlines and Shen (2005), making zoom-in and zoom-out operations is time-consuming. There are a few attempts to solve this problem using magnification lenses, as seen in the survey by Tominski et al. (2017).

FingerGlass (Käser et al., 2011), DTLens (Forlines and Shen, 2005), and OrMiS (Bortolaso et al., 2013) are multi-touch interfaces that explore human-computer interaction, focusing on zooming techniques and visual content manipulation. FingerGlass (Käser et al., 2011) offers a virtual lens for magnifying specific regions on smaller screens, DTLens (Forlines and Shen, 2005) allows multiple users to explore different parts of a map or diagram simultaneously, and OrMiS (Bortolaso et al., 2013) uses a virtual lens to focus on specific objects within a simulation for detailed exploration. However, no proposed approach was considered suitable for an environment that consists of analyzing and interacting with large maps with minimized context loss. Hence, the necessity of creating a new technique emerges.

The approach proposed in this paper, although applicable to any application with large-scale maps, is intended to be used in an integrated simulation environment for the Artillery of a national Army. This environment presents a tactical virtual simulator for training mid-rank officers in rocket launching activities using a saturation rocket system. It is necessary to note that the exercises are intended for one trainee at a time. This fact impacts the design of the solution, which, unlike other augmenting lens techniques such as those presented by Bortolaso et al. (2013) and Forlines and Shen (2005), does not have the intention to promote better simultaneous collaboration.

Our approach consists of a magnifying lens divided into two circles. The smaller one called the *indicator* is positioned by the user over the area of interest and has a small inner circle that indicates the amount of zoom applied. The larger circle called the *viewport* is adjacent to the indicator - just like an overview+detail display (Käser et al., 2011) - and covers only a small part of the context regardless of the amount of zoom, taking into account the concept of focus+context (Bortolaso et al., 2013).

We aim to introduce a magnifying glass that enhances the usability of interaction on large maps, particularly when highlighting and interacting in specific areas of interest. These features are designed to reduce the loss of context and enhance interaction efficiency, ultimately benefiting the user experience.

The remainder of this paper is structured as follows: Section 2 presents some fundamental concepts regarding magnifying glasses in tabletop environments. Section 3 describes related work and some specifications of the environment in which this technique must be implemented. Section 4 presents the method used in this paper as well as the proposed approach. Section 5 describes the validation methods used to validate the work. Finally, in Section 6, the results are presented and discussed. In Section 7, final considerations and suggestions for future work are described.

2 BACKGROUND

Tabletops have been widely adopted in various domains due to their capacity to facilitate collaboration and improve data analysis through interactive interfaces. They have been particularly effective in contexts such as education (Bortolaso et al., 2014), where students engage in collaborative learning activities and benefit from direct manipulation of educational content in a shared environment. In the healthcare sector, tabletops have been utilized to enhance medical diagnostics and treatment planning. The ability to display large volumes of data and interact with medical images in real time allows healthcare professionals to analyze complex datasets more comprehensively. For instance, the large surface area of tabletops makes it possible to display high-resolution medical images, which improves the precision of diagnostics and supports more detailed decision-making (Yang et al., 2014; Madni et al., 2016).

Additionally, in crisis management, tabletops have proven invaluable for situational awareness and decision-making during emergencies. Döweling et al. (2016) described their use in collaborative environments where multiple organizations, such as fire departments, police, and rescue teams, must coordinate their efforts. The tabletop's interactive interface allows participants to manipulate maps, annotate essential areas, and visualize real-time data, fostering an integrated approach to crisis resolution. This capability significantly enhances the ability to share critical information, develop action plans, and track resources in dynamic, high-stress environments.

Moreover, tabletops offer an intuitive and natural interface that leverages multi-touch capabilities, allowing multiple users to interact simultaneously. It fosters greater participation and engagement in group settings, especially when compared to traditional workstation-based solutions, which often limit the number of active participants. The panoramic view provided by tabletops not only enhances map-related tasks but also supports the visualization of large datasets across various domains. In health, for example, the number of elements that can be displayed on the screen allows more details about medical images to be seen, thus supporting better analysis and collaborative interpretation (Yang et al., 2014; Madni et al., 2016). In addition, as noted by Salvador-Herranz et al. (2016), tabletops also contribute to improving the efficiency and quality of teamwork, overcoming limitations related to screen size and interaction constraints found in more traditional computing setups.

It is essential to clarify some key terms used throughout this work to ensure a consistent understanding of the concepts central to our discussion:

- *Interest Area*: This refers to the specific area of the display that is being magnified. In the context of the proposed technique, the interest area is represented by the smaller circle within the magnifier (as illustrated in Figure 6). This area is of particular importance as it contains the detailed information that the user wants to analyze more closely, and the magnification is applied exclusively to this portion of the map or dataset.
- *Magnified Area*: Also known as the ”augmented area” or ”magnified view,” this term describes the enlarged version of the interest area. In the proposed model, the magnified area is rendered adjacent to, and tangent with, the interest area. This design ensures that users can easily correlate the zoomed-in details with the corresponding location in the broader context without losing sight of the surrounding elements. By maintaining this proximity between the magnified and interest areas, users can navigate between different levels of detail more fluidly, improving overall usability.
- *Context*: This term refers to the region surrounding the interest area, which remains visible but unaltered by the magnification. In systems where magnification techniques are employed, preserving the context is critical to maintaining spatial orientation and understanding how the zoomed-in details relate to the larger dataset. Without the context, users may struggle to interpret the magnified information in relation to the whole, potentially leading to confusion or errors in data interpretation.

Currently, as outlined by Cockburn et al. (2009), there are four primary magnification techniques commonly employed to facilitate information visualization on display devices:

- Zooming: This is the technique currently implemented in the simulator, where users adjust the magnification by zooming in and out of the display. However, a limitation of this approach is that it introduces a temporal separation between viewing the overall context and the magnified details. Users must repeatedly zoom in to examine finer details and then zoom out to regain a sense of the larger context, creating a disjointed and less efficient workflow.
- Overview+Detail: In this technique, the context and the magnified region are spatially separated on the screen. Typically, the user sees a smaller, zoomed-in window (detail) alongside a broader view (overview) of the entire dataset or map. While this method provides simultaneous access to both the magnified details and the general context, it requires users to mentally correlate the two different views, which can sometimes introduce cognitive load, particularly when switching focus between them.
- Focus+Context: This technique aims to provide a more integrated view by magnifying the interest area while distorting, but not entirely obscuring, the surrounding context. For example, a fisheye lens can enlarge the central area of interest while maintaining a recognizable but compressed version of the nearby context. This approach minimizes the need to switch between zoomed-in and zoomed-out views, allowing users to maintain situational awareness of the entire dataset.
- Cue: In this approach, not only the layout of elements within the display but also the way they are rendered is altered. For instance, particular objects may be highlighted, dimmed, or filtered out entirely based on the user's specific focus or query. This technique allows for more dynamic interaction with the dataset by emphasizing relevant details while de-emphasizing or hiding less critical information, thus guiding the user's attention efficiently.

3 RELATED WORKS

In the survey presented by Tominski et al. (2017), several types of interactive lenses were addressed. It is essential to notice that, according to the authors, an interactive lens is a tool to visualize part of a dataset and not only to magnify it. To categorize the techniques, the authors adapted the taxonomy presented by Shneiderman (2003). One type of interactive lens the authors approach is the one designed for multivariate data, i.e., for data organized in dimensions. This type of lens can be seen in Decal-Lenses by Rocha et al. (2018), which adapts itself to follow arbitrary surfaces. Another addressed lens type is the one to analyze geospatial data. Ma et al. (2020) introduce GTMapLens, a technique to visualize texts associated with geographical locations.

There are works that, despite not presenting interactive lens techniques, help to outline problems related to the traditional zoom technique and present their solutions, like Bettio et al. (2021) that presented a novel approach to assist the user in exploring datasets by guiding the navigation, and Dumont et al. (2023) that uses cartographic techniques to add visual cues to maps while the user is zooming, to reduce user disorientation. There is also research regarding the applicability of visualization techniques in different conditions, e.g., multi-device environments, as presented by Liu et al. (2023).

In this paper, we are interested in magnifying lenses and how to minimize context loss. There are various approaches to this problem. Käser et al. (2011) use a bi-manual approach, where one hand positions the magnifying lens and the other interacts with the augmented area. Thus, context is only occasionally lost when the magnifying lens is needed. There are lenses intended for data analysis, such as Forlines and Shen (2005), lenses that avoid the loss of context using distortion techniques (Carpendale et al., 2004), and even through transparency (Pietriga and Appert, 2008). Finally, the specific problem of magnification for military use on maps has been addressed in the work of Bortolaso et al. (2013), one of the main bases for our work.

We detail three works that were fundamental to the development of the proposed approach, aiming to facilitate the explanation of the design rationale.

3.1 DtLens

Aiming to allow groups to explore simultaneously high-resolution spatial data, DtLens was created to enable multiple augmenting lenses, which, besides detailing data, provide tools for the user to interact with it on the tabletop (Forlines and Shen, 2005). The tool uses distortion to avoid context loss and to bestow a pliable rubber surface aspect to the dataset. The tool provides a slider to adjust the magnification (Figure 1). This feature allows the user to easily change the magnification, even if it requires only one hand.

Figure 1: DTLens, from Forlines and Shen (2005).

3.2 FingerGlass

FingerGlass is a bimanual technique that allows the user to define an interest area with one hand and to interact with it using the other in a magnified view (Käser et al., 2011). The authors state that the user should use the non-dominant hand (referred to by them as ”coarse hand”) to determine this viewport and to make the interaction using the other one referred to by them as ”fine hand”). Figure 2 exemplifies a right-handed user.

This technique aims to decrease the loss of contextual data by setting the position of the magnified view tangent to the interest area instead of overlapping it. This way, the immediately adjacent area is preserved. This tool vanishes when the user releases the coarse hand to provide a faster interaction.

To adjust the magnification, the user can change the distance between the coarse hand fingers, which determine the viewport or the radius of the magnified view, by dragging the borders of it with the fine hand.

3.3 OrMiS

OrMiS (Orchestrating Military Simulations) is a tabletop application designed to train military officers on combat and strategic maneuvers with map-based tasks (Bortolaso et al., 2013). This tool provides

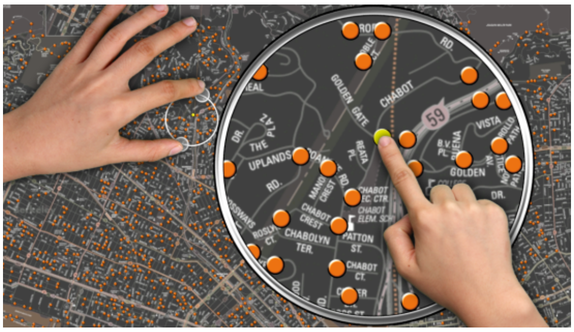

Figure 2: FingerGlass, from Käser et al. (2011).

lenses that enable users to work at different zoom levels, allowing interaction with specific parts of the map without disrupting the rest. This enhances simultaneous collaboration among trainees. (Figure 3).

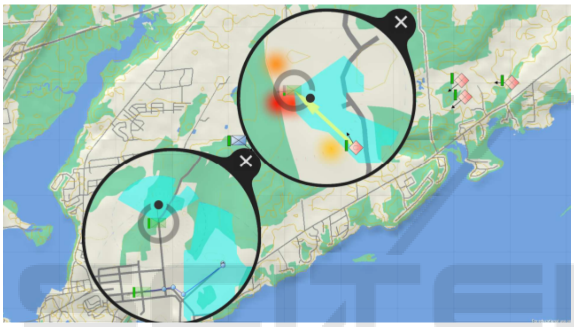

Figure 3: Lenses of OrMiS, from Bortolaso et al. (2013).

It is essential to point out that, unlike FingerGlass, the lens does not require the user's interaction to be shown. This feature enables the user to work on different parts of the map without closing it, which is vital in slow-paced interactions.

The user can adjust the zoom by making a pinch gesture and move the lens by swiping both movements inside the magnified area. These movements are intuitive and well-established in the human-computer interface community. However, they may be slow to use when applied in large datasets, requiring several repetitions of the pinch gesture to achieve the maximum or the minimum zoom available and the swipe action to move the lens expressive distances.

It is interesting to show that the authors found a way to deal with the context loss. Using an auxiliary screen, they combined the focus+context technique used in the lens with the overview+detail technique. The screen shows the entire map and highlights the part displayed with the current global zoom and the areas the lenses occupy. These areas are divided into two parts: the interest area and the loss context (highlighted with red) (Figure 4). Therefore, the users can see all the information hidden by their lenses and glimpse the magnification ratio they use.

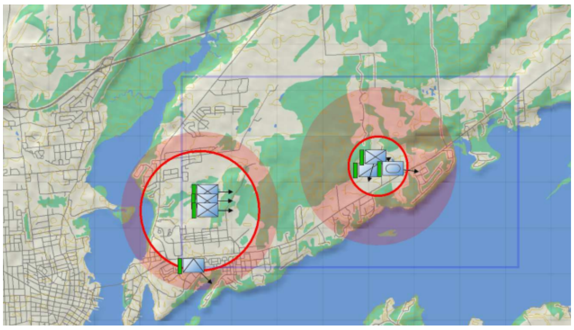

Figure 4: Map overview screen, from Bortolaso et al. (2013).

3.4 Conclusion

FingerGlass, DTLens, and OrMiS explore human-computer interaction in multi-touch interfaces, with a particular focus on zooming techniques and visual content manipulation. While they share the goal of facilitating interaction with data on touchscreens, each has specific features and applications. FingerGlass proposes a virtual lens to allow the user to magnify a specific region of the screen on a smaller screen tangent to the interest area, which is ideal for mobile devices such as smartphones and tablets. The multiple virtual lenses in DTLens allow multiple users to explore different parts of a map or diagram at the same time, facilitating collaboration on design and engineering projects. The virtual lens in OrMiS is used to focus on specific objects within a simulation, allowing users to explore the details of a system or process in a training environment.

Considering that each of the above techniques was designed for a specific environment (all different from the SIS-ASTROS Simulator), neither of them is suitable for the required type of interaction. Thus, the adopted solution combines parts of their approaches.

4 RESEARCH METHOD

The research method consists of four phases, as shown in Figure 5):

- **Identify Tactical Simulator Requirements.** In this step, we identified the critical usability requirements for a virtual tactical simulator that operates on tabletops and uses large-scale maps. The goal was to determine the essential features and interactions needed to enhance user experience using magnifying lenses in this specific context (see Section 4.1).
- **Propose New Approach.** Based on an in-depth analysis of related works and existing literature,

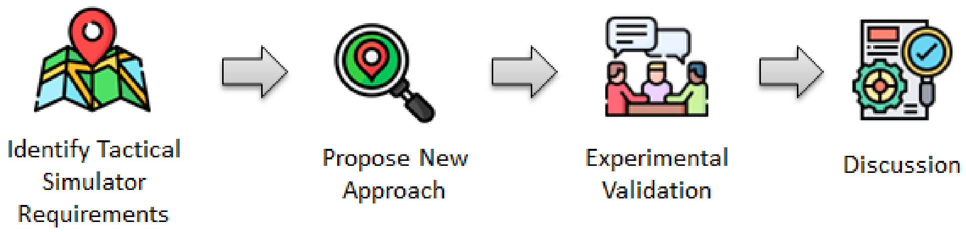

Figure 5: Research method.

we proposed new functionalities for the magnifying lens technique that were tailored to address the usability challenges identified in tactical simulation scenarios (see Section 4.2).

- **Experimental Validation.** We conducted a series of experiments to validate our approach, gathering both objective and subjective data as described in Section 5. The objective analysis measured performance improvements, while the subjective analysis captured user perceptions through well-established evaluation methods.
- **Discussion.** The results obtained were analyzed and discussed in Section 6, aiming to consolidate the findings and provide insights for further research and practical applications in tactical simulation systems.

4.1 Identify Tactical Simulator Requirements

The SIS-ASTROS Simulator for which we are developing this magnifier was designed to present two user-interface perspectives: two-dimensional (2D) and three-dimensional (3D). From a 2D perspective, the users interact with a map via a tabletop display. This touch-screen simulation tabletop, where we intend to implement the proposed magnifier, allows users to interact with the simulation, performing all the tasks described in the military doctrine for launching rockets. In technological terms, the digital tabletop is a capacitive touch-screen interface with 84” 4k resolution that allows multiple touches simultaneously. The 3D perspective presents the visualization of the simulated terrain, including bridge conditions and vegetation density, on a Wall-TV panel. A third component, the instructor’s control station, allows the instructor to configure simulation exercises through a 2D visualization interface, creating an entire operational situation that the trainees must examine. All these three elements are interconnected and synchronized.

The tasks performed in the simulator require precise control over zooming and panning while simultaneously maintaining awareness of the broader operational landscape. At this stage, several requirements were defined:

- *Quick switching between overview and detail:* Users must be able to transition seamlessly between a complete overview of the map and detailed views of specific regions. Traditional zooming methods often require repetitive zooming in and out, which disrupts the flow of analysis and can lead to cognitive overload.
- *Focus on areas of interest while preserving context:* It is essential to allow users to concentrate on specific areas of interest without losing sight of the surrounding context. Maintaining the spatial relationship between the magnified area and the broader map ensures that users do not become disoriented.
- *Intuitive gesture-based controls:* Users should be able to quickly adjust the size and position of the magnifying lens through intuitive gestures, ensuring that the lens does not obscure critical information outside the magnified area. It ensures that interactions are smooth and non-intrusive, enhancing usability.

  This approach is designed to minimize user fatigue, streamline interactions, and ultimately support more efficient decision-making in high-stakes tactical scenarios.

4.2 The New Proposed Approach

The new proposed approach was designed following Nielsen’s heuristics (Nielsen and Molich, 1990). Other heuristic works that were also relevant to the development - which are specific for tabletops - are de Franceschi et al. (2020) and de Franceschi et al. (2021), which discuss the importance of adapting usability heuristics and propose new heuristics for tabletops, respectively.

To meet the defined requirements for the virtual tactical simulator, we employed the following techniques: non-vanishing technique, minimizing the loss of context, and magnification adjustment, each described below. The implemented magnifying lenses can be seen in Figure 6.

4.2.1 A Non-Vanishing Technique

The technique presented in this paper is meant to be implemented in a simulator where the interactions are slow-paced and may lead to menu opening, which requires the user to use both hands. Hence, the feature of vanishing the lens when the user interrupts his contact with it presented in FingerGlass may not be adequate. It was decided that the best approach in this scenario was the one present in OrMiS and DtLens, which allows the user to interact with other parts of the environment without vanishing.

4.2.2 Minimizing the Loss of Context

In addressing the issue of avoiding context loss in the area of interest, we rejected the distortion approach due to its potential interference with usability, aligned with Bortolaso et al. (2013), as it would impair the visualization of symbols in the area. To minimize the loss of context, we opted for a strategy aligned with FingerGlass, where the enlarged area does not overlap the area of interest but finds itself tangent to it. This way, some contextual data will be lost, but only a tiny part of it will be lost once the augmented area covers only a part of the area adjacent to the interest area.

4.2.3 Magnification Adjustment

Regarding the magnification adjustment, we decided to use the slider presented in DtLens because it enables the user to change it with one hand (Figure 6). Also, due to the use of large maps in the simulator, the user needs to be able to adjust high levels of magnification without too much effort. The features presented by OrMiS and FingerGlass would not be suitable because they would require, respectively, too many pinch gestures and a considerable offset of the hands to drag the borders of the lens.

Besides the circular slider, in line with the overview+detail technique presented in OrMiS, a sub-indicator that surrounds the interest area is shown inside the indicator (Figure 6). The sub-indicator's radius varies according to the magnification rate, contributing to the minimized loss of contextual data because there will not be any element covering the area between the indicator - which has a constant radius - and the sub-indicator. Moreover, it provides the user with additional feedback on the current magnification rate, which contributes to a more intuitive interaction.

4.2.4 Lens Movement

The lens is moved by dragging the indicator instead of making a swipe movement inside the magnified view. This approach was chosen to avoid excessive workload in moving the lens throughout the tabletop once it consists of an 84-inch screen. Independently of the magnification and, thus, the radius of the interest area, the indicator keeps a constant size. If it had the same size as the interest area, with high magnification levels, it would be hard for the user to move the lens once the human finger is not as precise as a mouse input (Albinsson and Zhai, 2003).

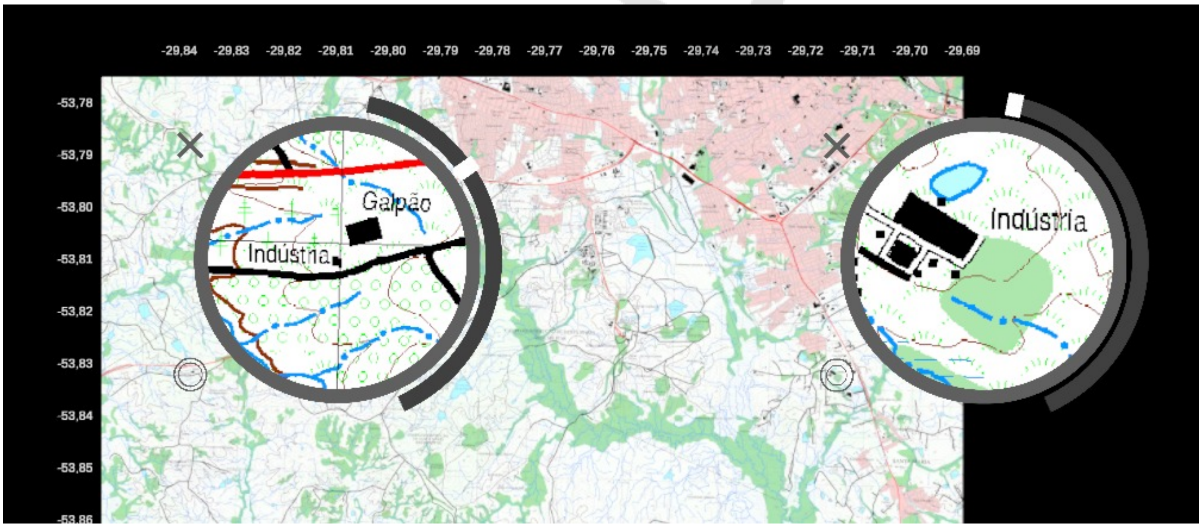

Figure 6: Two instances of our proposed magnifier. Each one has an *indicator* (The smaller circle) showing the amount and where the zoom is applied, and a *viewport* showing the augmented area. The slider allows the user to change the zoom amount.

5 VALIDATION

We opted for an ad-hoc implementation using C# and the Unity engine to evaluate the concepts applied in our magnifier. This approach provided a more agile and efficient way to test, focusing on validating the usability of the magnifiers without the immediate need to integrate such features into large-scale software.

The application consists of a section of a map representing a region. At the beginning of the test, the user is presented with a panel containing three random coordinates and a coordinate picker (Figure 7). The goal for the user is to select the requested coordinates on the map. Each participant performed the task twice, once using the traditional pan+zoom technique and once using our magnifiers. The order of the techniques was alternated for each participant to avoid training bias in the results.

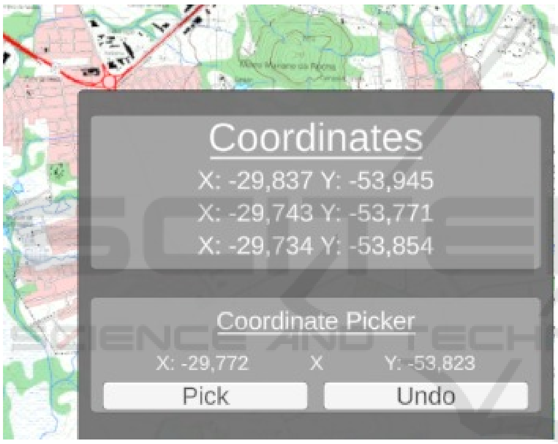

Figure 7: Coordinates panel.

The map has visual coordinate guides along its edges to help users position the marker (Figure 6). This information is lost when the participant zooms in to achieve greater precision. Conversely, if the user relies solely on the guides, they fail to select the coordinate accurately. The magnifier addresses this challenge by offering both precision and context preservation.

The experiment involved 20 students of Engineering and Computer Science (14 men and 6 women) between 20 and 25 years old (Figure 8), all of whom did not have experience with tabletop environments. They received a brief demonstration on how to use the touch table before starting the tests. The validation of our technique was divided into two parts. The first is an objective analysis, evaluating user accuracy and task completion time. The second is a subjective analysis using the NASA-TLX questionnaire after the test session.

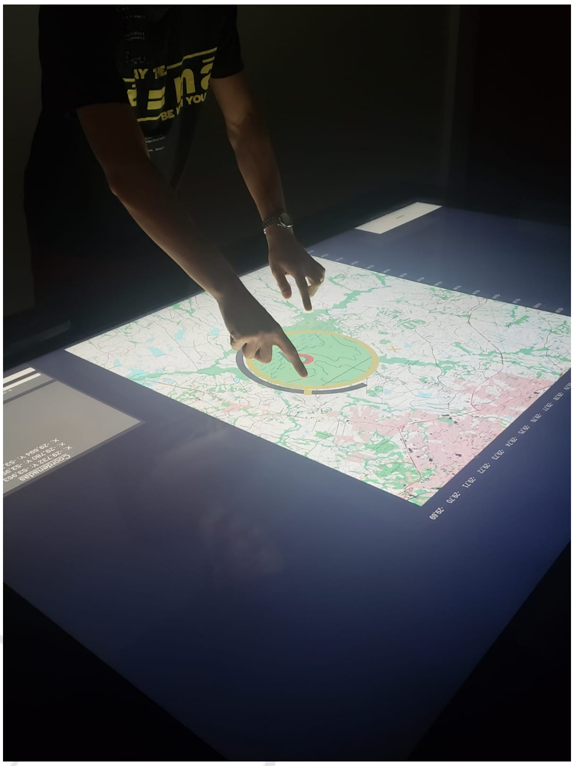

Figure 8: User testing the magnifying lens on a large-scale map.

5.1 Objective Analysis

To assess the impact of magnifiers on task execution, we recorded the time (T) it takes for the user to complete the task with and without the use of the tool, as well as the precision of the coordinates picked, similar to what is done in Albinsson and Zhai (2003).

5.2 Subjective Analysis

For the subjective analysis, this paper uses the NASA-TLX questionnaire. This questionnaire evaluates the workload of a determined task by calculating a weighted average between the ratings (varying from 5 to 100) given by the subject to assess the impact of six factors (Hart and Staveland, 1988). The six factors are Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Performance (P), Effort (E), and Frustration (F). The performance is assessed inversely: lower ratings indicate a greater significance. Table 1 shows the data collected during the experiment. The ratings will be multiplied by 5, once the range for the subject to pick is between 1 and 20.

In this study, the weights typically assigned by each participant to balance the relative importance of these factors were not collected, as the primary focus

Table 1: Data collected during the experiment.

User	Mode	Time	MD	PD	TD	P	E	F	Score
0	Pan+Zoom	221.75	17	7	16	5	10	13	0.9745
0	Magnifier	192.39	10	5	10	3	7	6	0.9639
1	Magnifier	104.96	10	10	15	8	10	5	0.9569
1	Pan+Zoom	97.90	5	10	5	5	5	5	0.9808
2	Pan+Zoom	246.41	15	10	10	12	15	10	0.9768
2	Magnifier	192.64	10	8	8	6	8	6	0.9942
3	Pan+Zoom	284.44	12	5	10	8	9	16	0.9946
3	Magnifier	186.22	10	8	10	12	8	13	0.9898
4	Magnifier	256.53	6	1	6	10	1	5	0.9946
4	Pan+Zoom	202.65	10	4	3	9	2	1	0.9811
5	Magnifier	185.60	8	4	5	6	5	3	0.9866
5	Pan+Zoom	103.98	15	8	8	4	10	12	0.9579
6	Pan+Zoom	207.93	5	7	11	11	2	6	0.9732
6	Magnifier	164.77	1	4	7	3	1	3	0.9981
7	Pan+Zoom	93.85	1	1	5	5	3	5	0.9896
7	Magnifier	98.53	5	2	5	5	3	2	0.9914
8	Pan+Zoom	204.15	6	7	11	6	7	6	0.7948
8	Magnifier	257.88	5	7	10	5	7	5	0.9007
9	Magnifier	253.08	15	5	18	10	10	5	0.9779
9	Pan+Zoom	259.06	16	5	12	10	10	4	0.9504
10	Pan+Zoom	276.13	14	17	13	12	11	11	0.9632
10	Magnifier	142.61	10	7	8	17	7	3	0.9743
11	Pan+Zoom	313.06	10	5	13	5	15	11	0.9686
11	Magnifier	272.33	12	7	15	18	10	8	0.9309
12	Magnifier	312.79	11	8	12	3	10	12	0.9741
12	Pan+Zoom	229.28	6	7	6	3	5	3	0.9577
13	Pan+Zoom	259.88	16	6	10	10	4	16	0.9310
13	Magnifier	219.62	12	6	12	14	7	6	0.9610
14	Pan+Zoom	204.47	5	10	5	10	15	10	0.9842
14	Magnifier	202.25	10	5	5	5	10	7	0.9723
15	Pan+Zoom	138.31	10	10	10	5	1	1	0.9791
15	Magnifier	150.41	5	10	5	5	1	1	0.9807
16	Magnifier	182.15	16	10	16	15	11	8	0.9849
16	Pan+Zoom	113.33	13	12	15	17	10	6	0.9901
17	Pan+Zoom	198.02	10	10	15	10	10	10	0.9739
17	Magnifier	139.33	5	5	5	5	5	5	0.9782
18	Pan+Zoom	152.19	7	14	15	5	13	3	0.9392
18	Magnifier	199.08	5	4	9	3	8	2	0.9809
19	Magnifier	96.66	5	8	2	18	5	5	0.9873
19	Pan+Zoom	147.17	10	5	8	15	8	2	0.9245

was on analyzing the individual scores for each category rather than the overall weighted score.

6 RESULTS AND DISCUSSION

As previously mentioned, to avoid training bias, some of the participants (13) began the test round using the pan-zoom technique, while the others (7) started with the proposed approach. Hence, the data is divided into two groups for the analysis. The first one presents data of both the zoom and the lens of the first round only (Figure 11), while the latter, the second round (Figure 12). After these individual analyses, we present the overall results (Figure 13).

For the first round (Figure 11), it can be seen that the Mental Demand (MD) of the lens is slightly higher, which is expected once it presents unfamiliar features for the users, who are in touch with the techniques around zooming, such as pinching and sliding on a daily basis. The lens presented a significantly lower Physical Demand (PD) and Effort (E) because

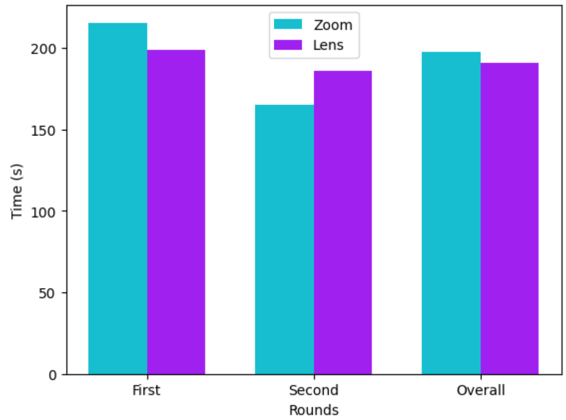

Figure 9: Average Time to Complete the Task.

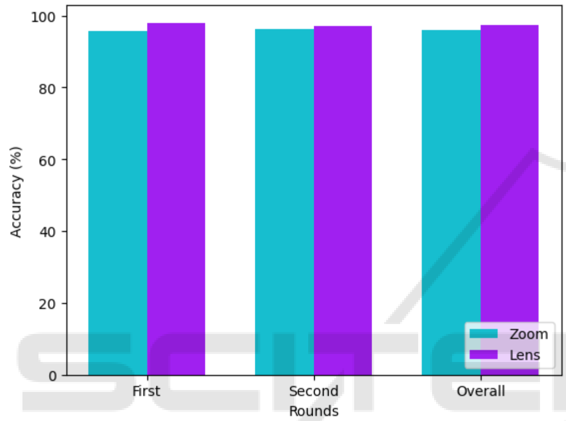

Figure 10: Average Accuracy of the Task.

it involved fewer movements to perform the task. Regarding the Frustration (F), it can be said that the lens outperformed the zooming technique as well, which indicates that, overall, the users found the lens to be more pleasant to use. Interestingly, the subjects felt considerable time pressure (TD) and felt that their performance using the lens wasn't as good as their performance using the zooming. However, as Figures 9 and 10 show, the average time to complete the tasks using the lens was lower and the accuracy higher, indicating that the users had high expectations of their performance using the lens.

For the second round (Figure 12), in general, the workload contributors' ratings decreased, which indicates that there is a learning curve regarding the use of the test environment. Another indication of this is the fact that the Mental Demand for the lens dropped while the zoom didn't change much, meaning that even a more complex tool can be easily used once the user has little contact with the environment. The subjects felt a higher frustration but still considered the effort to be lower. They felt a more significant time pressure using the lens. It can be seen in Figure 9 as

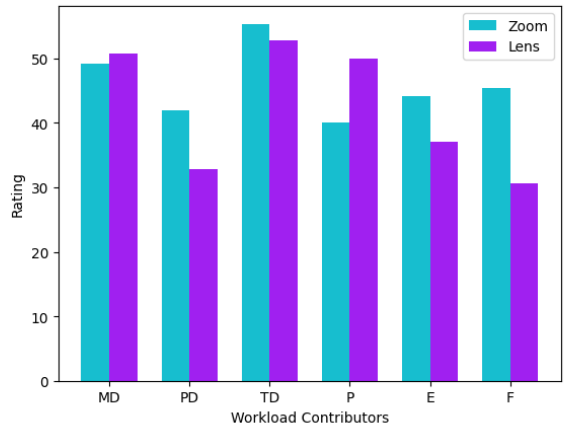

Figure 11: First Round Workload Ratings.

well, which shows that the user took a more significant time to complete the tasks. Nevertheless, they considered their performance with the lens to be better and had higher accuracy using it.

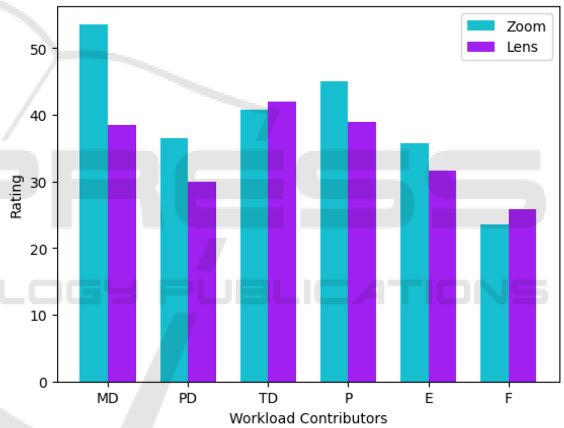

Figure 12: Second Round Workload Ratings.

Overall (Figure 13), the lens outperformed the zoom in every aspect but the performance, which, as mentioned before, is probably due to high expectations of the subjects, once the average accuracy and time to complete the tasks were better using it.

7 CONCLUSION

In the present work, we develop a new approach to improve users' interaction with large datasets in tabletop environments. We describe the design of a digital magnifying lens as a tool to highlight specific areas of interest on a map, aiming to minimize loss of context and improve interaction efficiency.

The results of the usability validation analysis revealed that the proposed magnifying lens helped the

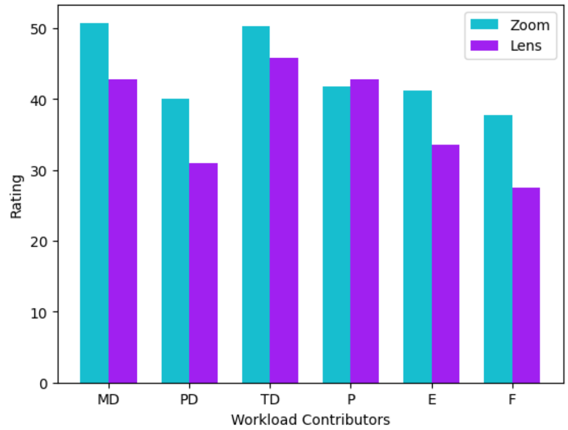

Figure 13: Overall Workload Ratings.

users to perform tasks involving high-precision coordinate picking on a large map. Both the time needed to finish the activity and the accuracy were better than the traditional pan-zooming. Moreover, the users felt more comfortable using the lens according to the NASA-TLX questionnaire results, in which the lens outperforms the zooming in all aspects except performance. As mentioned, this fact is probably due to the high expectations the subjects had with the lens once their performance using it was better in terms of the average accuracy and time to complete the tasks.

Given the positive result, implementing our technique over the traditional pan-zooming technique is worth it. Although the tests were conducted on a large tabletop for a military simulation project, it is worth noting that this technique can be used on other platforms, improving interactions in various types of applications, simulation environments, or serious games involving data analysis, interaction with maps, security, and surveillance, among others.

For future work, it is recommended that the magnifying lens be implemented in practical environments to evaluate its effectiveness in real contexts of use.

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