A Comparison of Traditional and Fisheye Radar View Techniques for Spatial Collaboration

Wendy A. Schafer Doug A. Bowman
Department of Computer Science
Virginia Tech
{wschafer, bowman} @ vt.edu

Abstract

The activity of spatial collaboration involves solving spatial problems related to a large, physical area. Representing this area in collaboration software is not trivial. Radar views are a popular technique for providing awareness information in shared representations. They indicate where each user is working and any overlaps in users' viewports. However, spatial collaboration requires more features than that provided by radar views. An enhanced design that uses fisheye techniques is offered and compared in empirical study with a traditional approach to radar views. Results indicate that the enhanced design has the potential to better support spatial collaboration activities and that users are divided on which technique they prefer. A discussion of results and suggestions for redesign are also proposed.

Key words: radar views, fisheye techniques, awareness, spatial collaboration, interactive maps

1 Introduction

Distributed collaboration occurs when people work together from different locations. For example, while collaborating on a project, one person might be at the office, another at his home, and the last on a business trip. Today's technology enables this type of collaboration and it is an everyday occurrence through the use of email, telephone, video conferencing, etc. Often, the context of such distributed collaboration is a large, physical, spatial entity such as a building floor plan or a natural area outdoors. For example, architects in different locations may need to discuss a set of blueprints or an environmental club may want to coordinate trail maintenance efforts. When distributed collaboration activities focus on spatial problems relating to large, physical areas this is termed *spatial collaboration*.

Email, telephone, and other distributed solutions may not be sufficient for spatial collaboration. This type of collaboration requires greater spatial support. For instance, email attachments and web pages allow people to exchange images, but this approach can be slow and tedious when carrying on an intricate discussion with many spatial references. One alternative is an interactive and collaborative representation of the area of interest. Such a representation can provide a spatial context for the activity and support a range of collaborative tasks. There are many design possibilities for such a representation. The representation could be two- or three-dimensional, it could incorporate different levels of detail, it could provide any number of viewpoints, etc. One approach is to use a 2D representation and enable individual exploration and interaction. This allows each user to navigate a complex representation on their own and perform individualized actions not visible to the others. For example, in distributed spatial collaboration, a collection of people designing a town park could benefit from individual views of the space and personal annotations about where to place objects.

Individualized viewports in a distributed setting present awareness issues. It is not easy to see who is participating in the activity, where they are working, and what they are doing [6]. For example, if two people are looking at the same town park representation it may be unclear to one where the other is looking without explicit instruction. Radar views are a popular technique for providing this awareness information in shared representations. They display a miniature of the entire workspace and indicate each collaborator's current viewport (Figure 2a). This allows each user to visually understand his view with respect to the space and with respect to the other users' views.

Applying the radar view technique to shared representations that require extensive zooming such as spatial collaboration representations seems like a natural extension of the idea, but usability problems are introduced [12]. An enhanced design that uses fisheye techniques is offered as a solution and compared in an empirical study with a traditional approach. Results from this study are presented, followed by a detailed discussion of the findings and suggestions for future use.

2 Related Work

Many different implementations of radar views have been developed and evaluated. They were initially described as part of the SharedARK system [14] and more recently they have been used in text editing tasks [1], laying out newspaper articles and creating concept maps [6]. In particular, Gutwin and Greenberg have shown their usefulness and usability in an empirical study [7]. Yet, this usefulness is not necessarily applicable to spatial collaboration solutions.

Fisheye views use focus+context techniques to present the details needed for local interaction, but also include a compressed view of the overall structure [4, 10]. Sarkar and Brown present a way to implement fisheye views for graphs using geometric transformations and they suggest unique transformations when working with maps [11]. These transformations make the map look more natural as it appears as if the map is projected onto a hemisphere.

Gutwin, Greenberg and Cockburn have previously explored the idea of using fisheye views with groupware [5]. In an initial investigation, they found that applying fisheye projections to a shared space could potentially help users maintain awareness information. They suggest fisheye techniques as an alternative to radar views. This project, on the other hand, uses fisheye projections within a radar view to enhance spatial collaboration.

3 Traditional Radar View Design

The simple awareness design of radar views is less usable for distributed collaboration when the shared representation is large and requires extensive zooming. Radar views are typically used with text documents and simple spaces that are navigated through panning interactions. Activities such as spatial collaboration, on the other hand, often require a complex representation that portrays a detailed space, such as a town or building. This representation is then navigated using panning and zooming techniques as well as levels of detail. The difference in these interaction techniques can present usability problems for radar views.

When users change the scale of their view through zooming, the size of their viewport representation in the radar view grows and shrinks. Large viewports are not a problem, but small viewports can be potentially difficult to use. A viewport representation may be too small to visually comprehend. Also, it may be difficult to determine if multiple, small viewports overlap.

Levels of detail in a shared representation can also cause usability problems. Radar views often provide an abstraction of the shared workspace rather than display all of the details. This approach requires users to discuss their individual views and not just examine the radar view. Yet, in a representation that incorporates zooming, the details in an individual's view often vary with the zoom level. For example, a representation of a town might be zoomed so that building outlines are added to the display. This level of detail technique is useful for a single user, but it can lead to problems in a collaborative system. Two users could be viewing the same area with different presentations. When the awareness information in a radar view only offers an abstraction of these views, the users have to resolve the differences through potentially lengthy discussions.

4 Fisheye Radar View Design

A fisheye approach to radar views addresses the potential problems of using traditional radar views with large, zoomable, shared representations. It maintains the basic design, adding a new feature that supports the zooming interactions and levels of detail used in complex spatial representations.

This new feature is the use of fisheye projections within the radar view. Fisheye projections are a technique that offer details and an overview within the same representation [4]. Mathematical functions magnify certain areas of the representation and demagnify others, while keeping the scale of the rest of the representation somewhat constant (Figure 1).

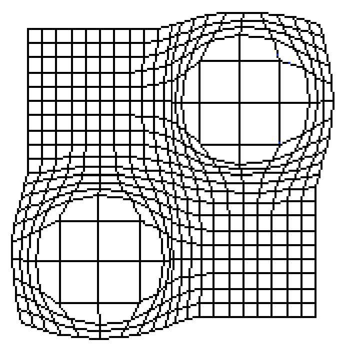

Figure 1. Applying fisheye projections magnifies and enlarges areas in a spatial representation.

In the enhanced radar view, fisheye projections are applied so that each collaborator's viewport representation is enlarged. This magnification has two consequences. First, it increases the size of small viewport representations. Viewport representations that were too small to visually comprehend with traditional radar views are now magnified in the enhanced version. This allows overlapping views to easily be discerned and it provides a more usable miniature.

Enlarging the viewport representations also allows more detail to be displayed in the radar view. Radar views often only provide abstractions of the shared workspaces because too much detail creates a cluttered miniature. Yet, enlarging areas of the radar view allow more detail to be displayed. One approach is to use the extra space in each user's viewport representation to render more of the individuals' views. This will provide the users with greater awareness about each other's displays, while maintaining the information about their viewport positions. Thus, reducing the potential collaboration problems.

Figure 2 shows a comparison of a traditional radar view (figure 2a) and a fisheye radar view (figure 2b). The user is working with a representation of the town of Blacksburg, Virginia and his viewport is outlined with a rectangle in the radar view. In Figure 2b, the viewport representation is magnified, creating a bubble effect.

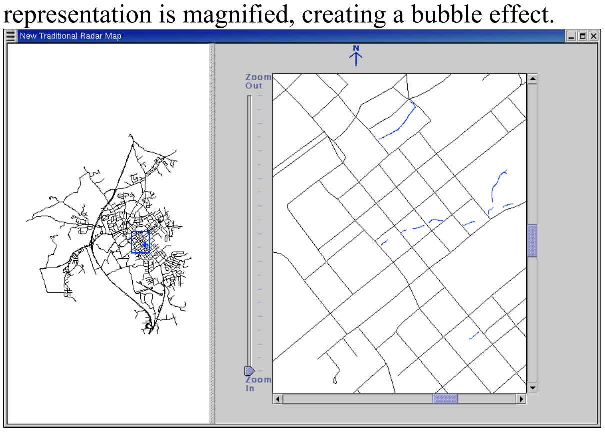

Figure 2a. A single user has zoomed into a detailed area on the right. A traditional radar view is displayed to the left. A crosshair indicates the cursor location.

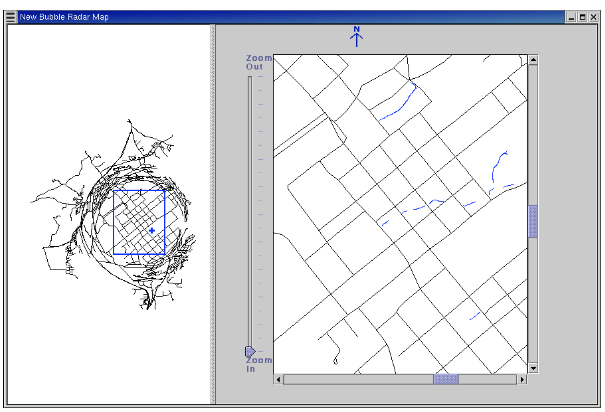

Figure 2 b. Navigating to the same location; the fisheye radar view more clearly indicates the viewport details and current cursor location.

The mathematical function used to create this effect applies a linear transformation to each coordinate in the map. Points located within the circle that circumscribes the user's viewpoint are magnified, points in a larger circle surrounding the viewpoint are demagnified, and the remaining points are not altered such that:

$$F(a) = a / \sqrt{D} \qquad (r < radius)$$

$$= \frac{a\,(radius)}{r\sqrt{D}} + \frac{0.5\,a\,(r - radius)}{r} \qquad (radius < r < E)$$

$$= a \qquad (r > E)$$

This transformation is applied to the x and y coordinates separately as each are placed in the function for **a** and where

- **D** is the ratio of the user's viewpoint size to the size of the entire map (D < 1)
- **r** is the distance between the point to be transformed and the center of the user's viewpoint
- **E** is the radius of the larger circle, which corresponds to the distance required in order to demagnify by a constant scale of 0.5

A weighted averaging technique handles multiple users to produce a multiple bubble effect. Using this approach, each point is determined by applying a weight to the results of each individual transformation. Our implementation follows Keahey's algorithm [8].

5 Experiment

An empirical study was conducted to compare the traditional approach and the fisheye design with respect to spatial collaboration. This investigation examined whether traditional radar views are sufficient for distributed, spatial collaboration and explored the effects of each technique. The hypothesis was that the fisheye design would correspond to greater congruency among the collaborators, faster task completion, reduced effort, and higher user satisfaction.

Users worked in pairs and completed four tasks in a within-subjects design. The conditions corresponded to the combinations of two radar conditions and two navigation conditions. The radar conditions were the traditional and fisheye approach, while the navigation conditions differed in the number of viewpoints available. Discrete navigation used discrete zooming and panning, dividing the representation into 3 zoom levels with 91 possible views. Continuous navigation offered a range of zoom levels and views. The ordering of the trials was counterbalanced using a Balanced Latin Square.

In all of the conditions the radar view represented each user's viewport with a different color. One user had a blue rectangle while the other viewport corresponded to a red rectangle. Small crosshairs in the same color scheme indicated where each user's cursor was located. These telepointers were only displayed when the mouse was located within the primary map display.

Users interacted with the map similarly in both navigation conditions. Yet, the discrete views resulted from a division of the space into non-overlapping views. The discrete possibilities included the zoomed out view, nine views resulting from partitioning the space into three rows and three columns for the mid-zoom level, and the views from dividing each of these nine views into three more rows and columns at the most zoomed in level. In the continuous condition, users were not constrained in their movements. They manipulated the display with fine and large adjustments.

Sixteen random pairs of people completed the experiment. Most were Blacksburg, Virginia residents, with a number of interests including biologists, English majors, computer scientists, and ecologists. Twenty males and 12 females participated. The average age was 30 with the youngest being 21 and the oldest 53. Pairing of participants was random resulting in 6 male-male pairs, 2 female-female pairs, and 8 male-female pairs.

5.1 Task

The pairs were asked to work together to position traffic lights and road signs in Maine towns. Each user was given a partial set of criteria in deciding on the positions. The sign criterion was open-ended such that users were guided to a general area and were asked to choose the location. The traffic light statements led to specific intersections (Figure 3).

After agreeing on a location, each user positioned a marker on his interface to indicate the position. The users could not see when the partner moved a marker and so they had to coordinate their actions to be sure they both marked the location. Also, telepointers were disabled when dragging a marker to encourage more collaboration regarding the agreed upon location and to prevent a simple alignment of telepointers.

This task did not control for differences in spatial abilities. Individual differences are one of the major issues spatial collaboration faces and it is important to explore whether these differences are supported. On the other hand, using towns in Maine controlled the users' prior spatial knowledge. Very few of the participants had been to Maine and those that had were not familiar with the towns used. This meant that all of the users had an equal level of spatial knowledge at the start of a task.

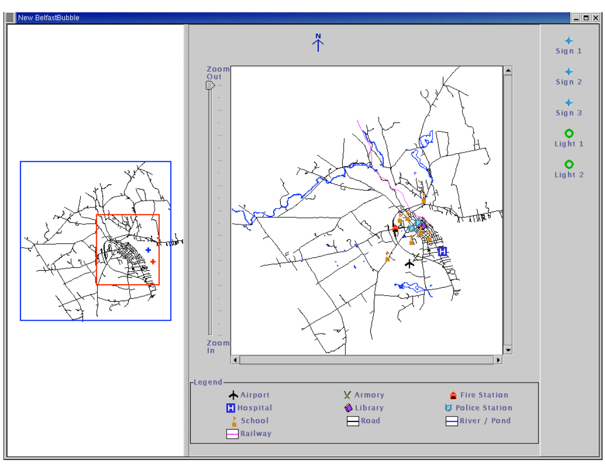

Figure 3. Experiment interface with a traditional radar view. The radar view shows each user's viewport and cursor position, the individual sign and light markers are to the right, and a legend appears below the map.

5.2 Procedure and Metrics

Each pair of users followed a similar procedure. After being introduced and reading through a set of instructions, the group completed four trials corresponding to the four treatments. Each user sat in a separate room with an audio channel connecting the users and the experiment administrator. Users worked with identical PCs and could freely talk and hear responses without worrying about headphones or microphones. Before collaborating with each Maine town, the pair explored the upcoming interface with a familiar map of Blacksburg, Virginia. Then, after completing the Maine task, the users individually rated the treatment condition. At the end of the trials, a final questionnaire asked each user to rank the four conditions with respect to collaboration, navigation and preference. Informal debriefing discussions were also conducted before the group left.

In addition to the surveys, a number of other metrics were collected. Software logs maintained where each user positioned his markers. This allowed a calculation of the difference between each user's marker position for the same light or sign. The time required to position each marker as well as the total task time were also recorded. Also, the sessions were videotaped and analyzed with respect to different strategies of use. The video recorded each user's face and computer screen.

6 Results

The results from this study revealed differences among the four treatment conditions. This section briefly summarizes the results for the two navigation conditions and focuses on the findings for the radar view techniques. A detailed discussion follows in Section 7.

6.1 Navigation Results

Comparing the results for the continuous and discrete navigation techniques, continuous navigation is clearly favorable. This style of navigation was associated with significantly better rankings in the final questionnaire as participants ranked the four trials with respect to ease of collaboration, preference, and ease of navigation. Similarly, the users indicated that continuous navigation requires less effort on the end of trial ratings. There also was a significant difference in the task completion times with respect to navigation as users took less time to position a light marker in the continuous condition.

6.2 Final Questionnaire Results

Many of the interesting results for the fisheye design relate to the final questionnaire. In this individual survey, two of the questions were straightforward asking which technique was better for collaboration and which technique was preferred. Three choices were provided: the traditional view, the fisheye view, and neither (about the same). Using the Chi-Squared Goodness of Fit Test when users chose one view over the other revealed that even though the frequency counts favor the traditional view statistically each view was chosen equally (collaboration: chi-squared = 0.73, $p < 0.05$; preference: chi-squared = 7.35, $p < 0.01$). The number of responses to each question is shown below:

	Traditional View	Fisheye View	About the Same
Which was better for collaboration?	13	9	6
Which did you prefer?	14	8	6

Table 1. Final questionnaire results when users were asked to choose between the two radar view conditions. Statistically, users were did not favor either condition.

Similarly, a Friedman Two-Way Analysis of Variance by Ranks revealed that users ranked the traditional and fisheye design equally. In the final questionnaire, three of the questions had the users rank the four treatment conditions. One ranking was based on how easy/hard it was to collaborate, another dealt with preference, and the last asked how easy/hard it was to navigate the map. Looking at the results for collaboration and preference, there was not a significant difference between the traditional and fisheye rankings within the continuous and discrete combinations. This implies that users did not find one technique easier for collaboration than the other and that they did not prefer one technique to another. This agrees with findings from the straightforward questions. The users also ranked the two continuous navigation conditions statistically equal with respect to which was easier to navigate. The sum of ranks for each condition is displayed below:

	Continuous		Discrete	
	Trad.	Fisheye	Trad.	Fisheye
Ease of collaboration	58	66	98	100
Preference	57	51	103	109
Ease of Navigation	48	53	101	118

Table 2. The final questionnaire had users rank the conditions. Within the same navigation condition, the sum of the rankings for the two radar views was equal.

Lastly, the final questionnaire directly asked which radar view design was easier to use. Similar to the other questions the choices were: the traditional view, the fisheye view, and neither, both were about the same. Here, users did not chose the traditional and fisheye approach equally often. Eighteen people selected traditional view, five people selected the fisheye, and five chose neither. Using the Chi-Squared Goodness of Fit Test indicates that the traditional view is considered easier to use (chi-squared = 1.64, $p < 0.30$).

6.3 Strategies of Use

Each group's session was video captured and reviewed afterwards. One observation of these recordings relates to the strategies the groups used. It seemed that the groups would typically use one of three approaches in positioning a marker after they understood the criteria. Frequently, they would have an intricate discussion about the shape of the roads with respect to the criteria. Other times they would use the radar map to simply point out a spot. The last strategy was a combination of pointing and a small conversation. For example, one user would indicate the spot and the other would confirm the location using a few nearby landmarks.

Each sign and light task that the groups completed was associated with one of these strategies in order to explore the different processes used. Analyzing the frequency counts of the discussion strategy in positioning the road signs revealed a significant difference. Even though users favored a discussion strategy overall, the number of discussions was greater with the traditional approach ($F = 14.24$, $p = 0.004$). Conversely, using one of the pointing strategies occurred more often with the fisheye design. The average counts for each condition are displayed in the table below:

	Discussion strategy	Pointing strategy
Traditional	2.36	0.64
Fisheye	1.93	1.07

Table 3. Average frequency counts for strategies used in positioning a sign marker. Discussions occurred more often with the traditional radar view, while the use of a pointing strategy was greater with the fisheye design.

6.4 Perceived Effort Ratings

At the end of each treatment, users rated the condition. Three questions asked how hard the task was to complete, how much effort it required, and how hard they had to concentrate. Answers were based on 7-point scale and averaged for a perceived effort rating.

Conducting an Analysis of Variance on these ratings revealed an interaction between the radar view and navigation conditions ($F = 4.46$, $p = 0.044$). In the discrete case the fisheye view had higher ratings, meaning that the tasks were more difficult and required more effort and concentration. Yet, in the continuous case the fisheye was associated with lower ratings (Figure 4). This is interesting because the fisheye technique was associated with easier task completion and less effort in the superior navigation condition. There was not a difference between the radar views within continuous navigation, nor a main effect of the radar view.

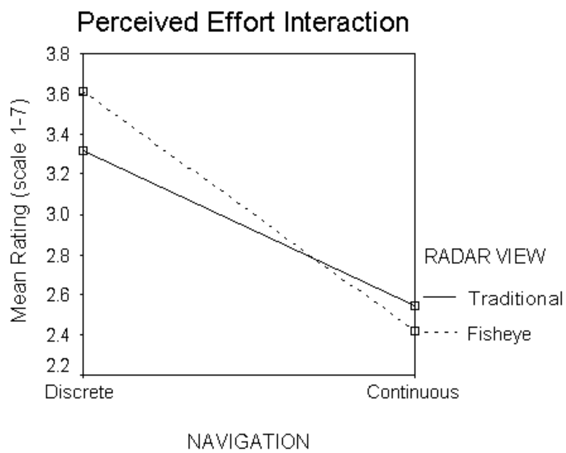

Figure 4. There was an interaction between the navigation and radar view conditions with respect to perceived effort ratings. Users felt that the fisheye view required less effort with the continuous case.

6.5 Task Completion Times

One interesting finding with the task completion times was another non-significant interaction between the radar view and the navigation conditions ($F = 3.60$, $p = 0.79$). Using the average time to position a sign, the fisheye tasks required more time for discrete navigation and less time in the continuous case (Figure 5).

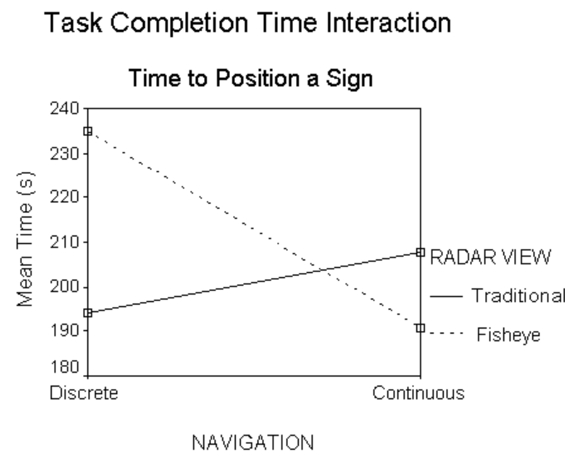

Figure5. There was a non-significant trend for an interaction between the conditions. Users took less time to mark a sign with the fisheye radar view in the continuous case.

6.6 Agreement Metric

The agreement metric did not indicate a difference between the two radar conditions. The hypothesis was that the users would be more in agreement with the fisheye design and place their markers closer to one another. However, a statistical analysis did not reveal any differences.

7 Discussion

The results of this study do not clearly demonstrate that the fisheye radar view is the better collaboration technique, yet they indicate the potential for a fisheye design and encourage further redesign and evaluation. Considering all of the results, the fisheye design had a positive impact on collaboration. In some analyses, it was associated with faster completion times and less effort. It also corresponded to greater use of a pointing strategy implying that the awareness tool is usable, efficient, and helpful for spatial collaboration.

In examining the individual results, it is particularly interesting to consider that the use of the discussion strategy was significantly greater with the traditional radar view, while the pointing strategy was used more frequently with the fisheye radar view. This indicates that the users relied on spoken discussions when the radar view did not provide them the awareness information that they required, particularly in deciding where to position a marker. This was directly observed in the experiment, where one participant would try to point out a location and the other would be unsure of the location, asking for a more detailed description of the spot or suggesting a different spot that perhaps both participants could easily recognize. The fisheye approach, on the other hand, enables one user to point at a location and the other user to understand where his partner is pointing with minimal verbal description. With its enlarged and pronounced viewport representations, the fisheye design affords pointing interactions. Each user knows that their partners have a "bubbled" version of their view so they often take advantage of this feature and express ideas through pointing.

It is also interesting to consider the interaction effects observed with respect to perceived effort ratings and task completion time. These results indicate that the utility of the fisheye approach differs with varying navigation conditions. Continuous navigation was clearly the superior technique for collaboration in the other analyses. Users consistently rated this condition as easier to navigate, easier to collaborate with, and requiring less effort. Task completion times were also significantly less using continuous navigation. Considering the fisheye's performance with the continuous navigation implies that it better supports collaboration, although the differences were not statistically significant.

Regardless of the differences in strategy and the interaction effects, many of the users in this study were unsure about the usefulness of the fisheye design. This was apparent in the final survey as users were divided on which condition was better for collaboration and which they preferred. During the trials, some users noticed the difference the bubble made while working together to decide where to place a marker. This group realized that the bubble was magnifying their viewport representations and they often expressed positive comments. Other users saw the traditional radar map as more intuitive and simply more pleasant to look at. To these users, the fisheye technique added another element of complexity for the collaboration activity.

One cause for these similar ratings may have been due to the metrics used. During the experiment, participants were observed taking advantage of the fisheye view's features without recognizing it. In one case, an experimenter directly watched the participant use the features repeatedly and yet state that he saw no difference between the conditions. Users would often become engrossed in the task at hand and fail to notice how the radar map was helping or hindering their progress.

There also was not a significant difference between the radar conditions for the agreement metric. This was mostly likely due to the implementation. The instructions asked the users to be as precise as possible, so they zoomed to the maximum level. This level often enabled many of the landmarks of interest to be displayed within the same view. A more extreme magnification would have caused the users to explore more zoom levels in positioning the markers, possibly leading to differences in precision and more conclusive results.

The only real negative result in the experiment for the fisheye approach was that the users found the traditional radar view easier to use. This again may be because the traditional radar map is more intuitive to novice users than the fisheye view and its distortion effect. Possibly with further use, this and other user ratings would change. However, the fisheye condition can also create problems with respect to how users point out features to one another. The transformation of the fisheye view may be confusing in that it is not clear whether the telepointer's position has also been distorted. Also, when one user points out a location to the other, it may be more difficult to determine where they are pointing if the telepointer falls within the demagnified part of the distortion directly adjacent to the magnified area. This can happen when one user is zoomed in and the other is not. Given these and other issues, the fisheye technique can be improved so that it more usable. Iterations of the design and further evaluation will lead to a more usable technique.

8 Improving the Fisheye Technique

In conducting the empirical study, a number of usability issues with the fisheye technique were revealed. In particular, the boxes that represent each user's viewport can often be confusing. For instance, the boxes can misrepresent the users' zoom levels. The fisheye technique transformation magnifies the viewing area based on each user's zoom level, but the boxes can often be similar in size when viewing different zoom levels due to the combined transformation function. The fisheye technique is also confusing when someone is navigating. All navigation movements, including a slight shift in a viewport to the left or the right, cause the transformation to be recalculated and all of the boxes change in shape and size. This is bothersome when one user is not interacting with the software and yet another person can affect their radar view.

To improve these usability issues, the transformation function should be modified and visual cues should be added to the fisheye view. One improvement would be to determine a more appropriate technique for combining multiple fisheye magnifications. The current approach of using a weighted average of the individual fisheye transformations [9] is problematic in that the presentation does not always correspond to expectations. Using 3D distortion techniques should be explored as an alternative [3]. Another way to improve the fisheye design is to allow the individual users' radar views to differ. Using a different transformation function for each radar view allows the local user's viewport box to stay fixed as other users navigate. Then, instead of recalculating a shared transformation function, each radar view uses the stationary, local viewport to determine how to display any changing viewports.

Also, adding visual cues to the fisheye display could better inform the users about zoom level differences and the transformation's effects. One approach to reduce the confusion is to associate the space with a checkered grid. Drawing this checkered grid so that it does not overwhelm the map content and so that it is visible behind the magnified portions of the radar view could provide relative zoom level information. Many small squares in the background of a viewport box would indicate a zoomed out view while a few large squares would correspond to a more zoomed in view. Applying a background grid, similar to latitude and longitude lines, could also improve the users comprehension of fisheye distortion. Transforming the grid in addition to the spatial representation indicates the magnification and compression effects used [2].

Another improvement would be to provide user controls for interacting with the fisheye transformation. Such controls should allow users to toggle the fisheye on and off as well as control the magnification factor. Enabling users to manipulate the fisheye may reduce their confusion by allowing them to explore the concept and learn about the visual effects produced. Yet, it also requires users to spend more time and effort in interacting with the radar view. This could lead to undesirable views or further confuse the users. It is important that future redesign and evaluation explore this tradeoff.

In conducting this study, it also became apparent that the fisheye radar might be more beneficial in certain tasks than others. For example, in the traffic engineer scenario, the fisheye was most helpful as the participants were deciding the final position of the marker. It was less helpful as the users examined the map for key landmarks. The fisheye technique may have even caused users to not understand a landmark's location within the space because of the distortion.

Similarly, the fisheye view may offer a greater benefit when working within a detailed area or a large, complex representation. This study used fairly simple road maps, but the fisheye technique could reduce the collaboration issues of more extensive representations. For instance, a fisheye radar view of a large metropolis might be more appropriate. In spatial collaboration, there are no boundaries on the size or complexity of the area being discussed. Fisheye radar views are unique in that they can support this range of applications.

9 Conclusions

Supporting spatial collaboration requires an investigation of representation techniques. One approach is to use a 2D representation and enable individual exploration of the problem space, yet this introduces awareness issues. A fisheye radar view is an enhanced version of a popular approach to providing awareness information. This technique has the potential to address some of the usability problems of applying radar view to spatial collaboration tasks. In particular, an empirical study identified promising results for the novel technique as well as suggestions for improvement. Users were divided on which approach they preferred and they favored a pointing strategy with the fisheye design. With more iterative design and evaluation, fisheye radar views can offer exciting solutions to spatial collaboration issues.

Acknowledgements

The authors wish to acknowledge Craig Ganoe and Dennis Neale for their help with the experiment, as well as Mary Beth Rosson, John Carroll, Christopher North, and Robert Morrill for their comments.

References

[1] Begole, J.M.A. Flexible Collaboration Transparency: Supporting Worker Independence in Replicated Application-Sharing Systems. PhD Dissertation. Virginia Tech, 1998.

[2] Carpendale, M. S. T., Cowperthwaite, D. J. and F.D. Fracchia. Making Distortions Comprehensible. *IEEE Symposium on Visual Languages*, pp. 36- 45, 1997.

[3] Carpendale, M. S. T., Tigges, M., Cowperthwaite, D.J. and F. D. Fracchia. Bringing the Advantages of 3D Viewing into Focus. *IEEE Conference on Information Visualization,* pp. 17-20, 1998.

[4] Furnas, G. The fisheye view: A new look at structured files. Technical Memorandum 82-11221-22, Bell Laboratories, 1982.

[5] Greenberg S., Gutwin, C. and A. Cockburn. Awareness Through Fisheye Views in Relaxed-WYSIWIS Groupware. *Graphics Interface*, pp. 28-38, 1998.

[6] Gutwin, C. and S. Greenberg. A Descriptive Framework of Workspace Awareness for Real-Time Groupware. *Computer Supported Cooperative Work, The Journal of Collaborative Computing*. 11(3-4), 2002.

[7] Gutwin, C. and S. Greenberg. The Effects of Workspace Awareness Support on the Usability of Real-Time Distributed Groupware. *ACM Transactions on Computer-Human Interaction* 6:3, pp. 243-281, 1999.

[8] Keahey, T.A. Nonlinear Magnification. PhD Dissertation. Indiana University, 1997.

[9] Keahey, T.A. and E.L. Roberson. Techniques for Non-Linear Magnification Transformations. *IEEE Visualization,* 1996.

[10] Lamping, J., Rao, R., and P. Pirolli. A focus+context technique based on hyperbolic geometry for visualizing large hierarchies. *Human factors in Computing Systems,* pp. 401-408, 1995.

[11] Sarkar, M. and M.H. Brown. Graphical Fisheye Views of Graphs. *Human Factors in Computing System,* pp. 83-91, 1992.

[12] Schafer, W. and D. Bowman. Enhancing Radar Views Using Fisheye Techniques. In conference supplement of *Computer Supported Cooperative Work* pp. 147-148, 2002.

[13] Schafer, W.A., Bowman, D.A., and J.M. Carroll. Map-Based Navigation in a Graphical MOO. *ACM Crossroads* 9.1, pp. 8-15, 2002.

[14] Smith, R. B., O'Shea, T., O'Malley, C., Scanlon, E., and J. Taylor. Preliminary Experiments with a Distributed, Multi-Media, Problem Solving Environment. *First European Conference on Computer Supported Cooperative Work* 19-3, 1989.