Multi-View Proxemics: Distance and Position Sensitive Interaction

Jakub Dostal
School of Computer Science
University of St Andrews, UK
jd67@st-andrews.ac.uk

Per Ola Kristensson
School of Computer Science
University of St Andrews, UK
pok@st-andrews.ac.uk

Aaron Quigley
School of Computer Science
University of St Andrews, UK
aquigley@st-andrews.ac.uk

ABSTRACT

We present work at a previously unexplored intersection of two research areas: proxemic interaction and multi-view display technologies. Multi-view proxemic systems concurrently deliver distinct views from a single display to different viewers depending on a combination of their *angle* to the display and their *distance* from it. In this paper we demonstrate the capability to design such an interactive system using only commodity hardware and software. We describe two systems and present results of two user studies with 18 participants. The studies are based on two real-world scenarios of a departure board and a video player (with subtitles). Our results show that multi-view proxemic systems are accurate and that users find them useful and would use them if they were available. We also discuss some of the design and technological implications of our work.

Categories and Subject Descriptors

H.5.m. [**Information Interfaces and Presentation (e.g. HCI)**]: Miscellaneous

General Terms

Design, Human Factors

Keywords

Proxemics; multi-user; multi-view; multi-view proxemics

1. INTRODUCTION

People naturally shorten their distance to objects to inspect them in more detail. This shortening also applies to computer displays in both public and private settings. Consider for example someone moving a small personal device, such as mobile-phone, closer towards them [4], or someone leaning closer to a desktop display [8], or even someone physically moving closer to a large display [17] in order to see more details. Currently, from the user's perspective, such motion only affects the resolution and potentially the perspective of the viewed display. The distance between display and viewer is typically unknown to the system.

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PerDis '13, June 04 - 05 2013, Mountain View, CA, USA

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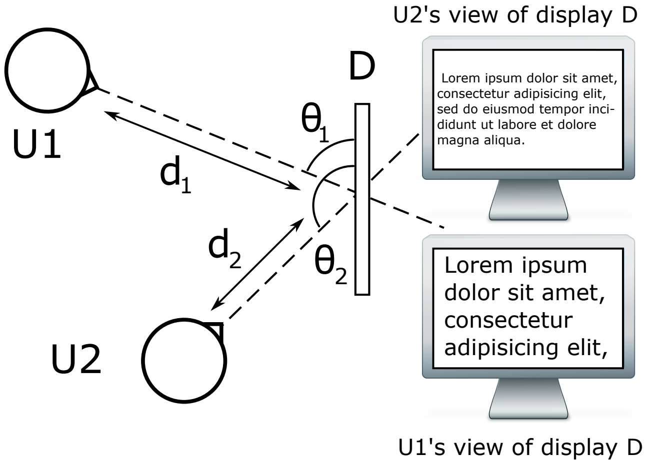


Figure 1. Two users viewing the same display with different distance-sensitive views from different angles. Each user sees different content.

In contrast, proximity-aware user interfaces [2, 4, 8, 17, 13, 14] attempt to measure the viewing distance between the user and the display in order to adapt the interface for a single viewer. Such user interface adaptations can range from the disruptive (e.g. ambient to personal space changes [17]) to intrusive (e.g. interface zooming [8]). Changes might also be considered subtle or undetectable [4] while still adapting to distance. Our research suggests that viewing distance can act as an input modality for interactive systems while making changes across this spectrum of user awareness levels [4].

However, displays are not always used by just a single person. Larger displays are commonly used by multiple people, for example, when watching a movie or reading a public information display. In addition, displays are viewed by people at varying angles. Therefore, distance adaptations that may be suitable for one person may have a negative impact on the viewing experience of other people.

In this paper we first expand the notion of proxemic interaction by incorporating horizontal and vertical viewing angles as parameters. We then present the first systems and studies of a single display used to generate simultaneous multi-user, distance-sensitive views from different angles. Finally, we discuss some of the design and technological implications of our work.

2. PROXEMICS

To situate this work, we provide a high level timeline of key proxemic literature as it relates to distance based computer interaction. Edward Hall's 1966 book *The Hidden Dimension* defines *proxemics* as the cultural concepts of space and how space affects our personal and societal relationships [7]. This book is often cited as the starting point for proxemic research. In 1998, Bradski [2] developed a computer vision algorithm that allowed tracking of the head position and its distance from a camera. In 2003, Streitz et al. [15] presented an interface called Hello.Wall that changed its functionality based on a person's distance from the wall. The following year, Vogel et al. [17] used Hall's notion of proxemics to define four interaction zones. Their contribution was extended by Ju et al. in 2008 [10], who further refined the idea that interaction becomes more personal and explicit as the user moves closer. In 2010, Ballendat et al. [1] broadened the notion of proxemic interaction to include objects, digital devices as well as using distance as a continuous, rather than zone-based, measure. Recently, Wang et al. [18] extended this conceptual framework by considering not only continuous distance but also a measure of attention towards the display. We also explored attention in proxemic interactions by considering a person's visual focus [6].

The lessons from the literature include the use of non-contact sensing of distance, explicit versus implicit interface adaptation, and interaction coupled to distance as a means for control. Our work extends the existing body of knowledge by expanding the notion of proxemics to include the horizontal and vertical angles of view as important parameters for proxemic interaction.

3. MULTI-VIEW DISPLAYS

With a view to incorporate viewing-angles into proxemic interfaces we examined technologies enabling multiple views on the same display. Most of these technologies use either spatial or temporal multiplexing. Systems using actively synchronised shutter glasses or passive polarised glasses employ displays (or projectors) with a high refresh rate to display interlaced frames for each eye. While the interlacing of the content is generally not noticeable with a sufficiently high refresh rate, the systems are very resource intensive and require user augmentation with glasses. Spatial multiplexing displays, such as those using lenticular sheets or parallax barriers do not require user augmentation but instead reduce the effective resolution of the displays. See Dodgson [3] for a more detailed overview of multi-view technologies.

There is another method for displaying multiple distinct views of a single display. Unlike the previous methods, it can take advantage of either temporal or spatial multiplexing and it does not require user augmentation. It is based on the specific properties of TN LCD displays. It was first described by Harrison and Hudson in 2011 [9] and was explored more in-depth by Kim et al. [11] in 2012 with dual views. The method relies on the specific compression of visible colour space of TN displays at different viewing angles to produce two distinct views using colour manipulation. With the availability of inexpensive TN LCD displays, this method lends itself for use in proof of concept prototypes such as ours. We designed two working systems demonstrating some of the aspects of the three dimensional proxemic interaction space we define in the next section.

4. DUAL-VIEW PROXEMICS

The design space for applications using distance as well as viewing angles is potentially very rich. We sample the design space from three perspectives and provide examples of applications and interaction techniques.

Using distance (e.g. d_1 or d_2 in Figure 1) between the interaction surface and a user provides opportunities for user interface alterations or control along the axis formed by the line between the user and the surface. However, adding knowledge of the angle of view to the surface (e.g. θ_1 or θ_2 in Figure 1) along the horizontal axis and using a display capable of generating distinct views at different angles allows for a much more fine-grained control. This also applies to the vertical axis, although making the user jump or squat to see a different view may not be practical. Visualisation of complex information is an example of possible use. Each of the different axes could be used to control a different aspect of the visualisation. For example, the distance could control the amount of detail visible, while the horizontal angle of view could be used to control the temporal progression and the vertical angle of view could provide alternative views of the data. This example would work equally well for single and multiple users.

Use in strictly multi-user scenarios is even more compelling. New sharing and collaboration techniques could be developed to take advantage of the additional information about location. Imagine a system that would dynamically shift between public, private or shared views for each user depending on their position and viewpoint overlap with other users. Different strategies for sharing such as distance-dependent screen splitting could be employed when the same view is shared by multiple users. When the each user sees a different view, the views could be used for further (perhaps subtle) personalisation. For example, the size and shape of text could be adapted based on the distance and viewpoint to maintain readability.

In order to demonstrate the possibilities, we chose two practical applications. The VIDEO scenario uses multiple concurrent views to selectively display or hide subtitles (see Figure 3), while simultaneously adapting the size of the subtitles to keep their size constant from the viewpoint of the user, who sees them. The TRAIN system simultaneously renders two separate views to people approaching the display from different distances (see Figure 2). The first view (Figure 2a) shows a static set of information for viewing from a long distance away. The second view (Figure 2b) shows one of two distance-dependent interaction zones. The chosen application examples cover both single user and multi user cases and explore the usage of the angle of view on the horizontal (VIDEO) or vertical (TRAIN) axes.

5. USER STUDIES

For this paper, we chose two application scenarios to demonstrate the possible applications for systems that alter the user interface based on the distance from the display as well as the angular viewpoint. We also wanted to elicit people's opinion about the potential usefulness of such systems in real-world scenarios. Since these are proof-of-concept systems, one of the design goals was easy replicability using consumer-level technologies, where possible.

5.1 Multi-View Display

In order to generate two distinct views on a single display, we adapted the method presented by Kim et al. [11]. Using a TN LCD significantly reduced the cost of deployment compared with other technologies. In our studies we used a 24″ Iiyama ProLite E2407HDS display. The colour compression used to create the two views is most visible along the vertical axis of the TN LCD display. We used spatial multiplexing to interlace the two generated views.

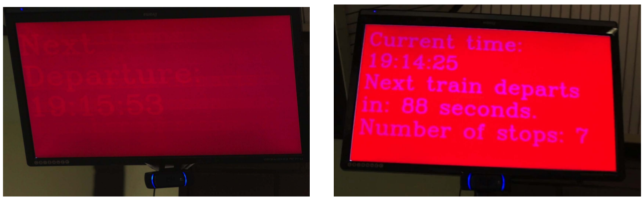
The prototype in the TRAIN scenario, has three interaction zones. However, since the two closest are distance-sensitive, our system only needed to show two distinct textual views (one for the two dynamic zones and one for the static zone). The display was in its default landscape orientation as we intended for the distinct views to be located along the vertical axis. Primary colours were reported to provide the most contrast by Kim et al., so we primarily concentrated on those when choosing the colours of the text and background. Unfortunately, the multiplexing of the two views led to colour interactions, which changed the perceived colour and contrast when the two distinct views were shown simultaneously. This meant that while the text was readable as expected, the overall colour scheme was not very pleasing to the eye. However, since the system achieved its design goals of generating two distinct views, we chose to continue with it for the purpose of our validation study.

For the VIDEO scenario, we used the colour compression to hide subtitles, while affecting the displayed movie as little as possible. This meant that unlike in the TRAIN scenario, we only needed our text to be visible in one of the two views. This meant that we did not need to multiplex the views and thus were able to use the full resolution of the display. Additionally, it allowed us to choose the optimal colour in terms of contrast and subtlety. Using a specific shade of green (RGB(0,15,0)) as the background of the letterbox surrounding the movie and a brighter shade for the subtitles (RGB(0,90,0)) enabled us to display two distinct views approximately 40° apart. We used the LCD display in portrait orientation to place the two views along the horizontal axis so that two persons sitting next to each other would see different views.

5.2 Sensing Distance

The ability of our systems to sense the distance of users is based on our earlier work on distance detection using computer vision [4]. We created a method for detecting viewing distance using off-the-shelf cameras and computer vision algorithms. Other systems capable of detecting user distance are primarily marker based (see [1, 17, 8] for examples). In contrast, our method does not require any user augmentation and can be directly applied in real-world settings.

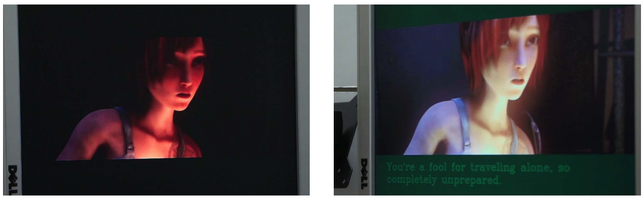
In our systems we used a modified version of a two stage feature detection algorithm [4]. Originally, in the first stage, an eye-pair was detected. If the search was successful, the second stage attempted to detect the left and the right eyes separately. If both of the eyes were successfully located, the distance from the camera was computed based on the distance between the pupils. To speed up this algorithm, we added an extra step to the initial search for an eye pair. This step was activated only when the location of the eyes



(a). User 1: Passive view visible when the user is far away from the display

(b). User 2: Active view visible at a medium distance from the display

Figure 2. The multi-view proxemic display observed by users 1 and 2 in the Train scenario. Images are for illustration only due to difficulty in capturing colours and contrast in real use on a digital camera.



(a). User 1: Passive view

(b). User 2: Active view with subtitles visible

Figure 3. The multi-view proxemic display observed by users 1 and 2 in the Video scenario. Images are for illustration only due to difficulty in capturing colours and contrast in real use on a digital camera.

was known from the previous iteration of the algorithm and the system's confidence in that detection was high (both the eye-pair and each of the eyes were successfully detected separately). This extra step limited the search area to a 25% of the camera image surrounding the last known location of the eyes. This increased the speed of the eye-tracking algorithm by a factor of two, while guaranteeing that the modified algorithm performed no worse than the original.

The computer vision only system used in this paper achieves the highest accuracy after a per-user calibration. However, a further extension of our approach completely eliminates this requirement and can be used as a drop-in replacement [5].

5.3 Participants

The same set of participants were used in both studies. 18 participants (10 female) were recruited among university staff and students (ages 20 to 36, mean 22.5, three wore glasses). Eight of the participants had a technical background (>1 year of Computer Science or related studies), while ten were from a range of other disciplines. No participants had been exposed to any similar system in the past.

We used a within-subject design for out studies. There were two conditions in each of the two studies, four in total. In order to counter balance bias due to possible learning effects, the ordering of scenarios and conditions of each user study was determined with a latin square. Before participation, participants were tested to confirm that each system was reliably capable of detecting their eyes and measuring distance. All tests were successful.

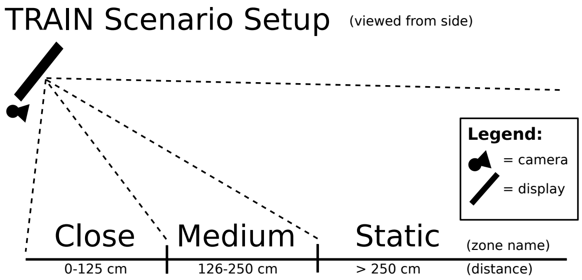


Figure 4. A diagram of the setup for the Train scenario. The Static zone is distance-sensing independent, while the display of the Medium and Close zones depends on the distance of the user closest to the display.

6. SCENARIO 1: TRAIN BOARD

The purpose of the TRAIN scenario was to create a system that introduces interactivity to a train station board, showing information about departing trains. Most current train station displays cycle through static information about the time of departure, departure platform and so forth. Our system retains this functionality while introducing two additional interactive views that display more detailed train information depending on users' distances to the display.

6.1 Procedure

The setup for the TRAIN scenario is shown in Figure 4. The interactive space in front of the display is divided into three zones (CLOSE, MEDIUM, STATIC) using distance sensing and different angles of view. The STATIC zone was not interactive and it was created to replicate information on current displays at train stations. Visible from the static zone was a screen cycling through information about the current time, time of the next departure and the terminus of the next train. This zone was created by allocating one of the two viewing angles of the display and it was designed to be visible at distances greater than 250 cm. The MEDIUM and CLOSE zones were created using a combination of the second viewing angle of the display and our distance-sensing sub-system. The MEDIUM zone was visible when the participant was between 125 cm and 250 cm away from the display and showed information about the current time, a timer to next departure and the number of stops the train would make. The CLOSE zone was visible when the participant was between 0 cm and 125 cm away from the display and displayed a timer to next departure and a list of all the stops the train would make.

For each scenario, two conditions were tested—we refer to them as the ACTIVE and PASSIVE conditions. In the PASSIVE condition no explicit user movement was required to complete a task, whereas ACTIVE meant a participant had to move to complete a task. For each condition, the procedure followed a similar pattern. First, the participant was introduced to the task they would perform. In the TRAIN scenario, the primary task was to gather information on departing trains.

The participants were also presented with a numbered answer sheet for questions relating to primary performance measures (questions related to information graphically or textually presented on screen). After completing their task, participants were asked to complete a questionnaire related to the secondary measures, verifying the functional performance of the system (e.g. readability of the text on a display). After both the ACTIVE and PASSIVE conditions were tested, the participants were asked to complete one final questionnaire regarding the perceived qualities and usefulness of the application within these scenarios.

In each condition (ACTIVE, PASSIVE), there were three trains leaving the station within the five minutes allocated to the task. In the PASSIVE condition, each participant was asked to remain stationary at a point 5 metres from the display to ensure they saw the STATIC view. In the ACTIVE condition, participants were encouraged to move and explore the interactive space. In this condition, the questionnaire was developed to make it impossible to answer all the questions without moving between zones.

6.2 Results

To ensure users can accurately perceive the displays we examined the correctness of the answers to the factual questions the participants were presented with (e.g. "How many stops does this train make?"). Each participant was asked 6 factual questions for the PASSIVE condition and 12 questions for the ACTIVE condition (18 answers per participant in total). The three extra questions for the ACTIVE condition were included to ensure the participants would have to use all three interaction zones. All of the resulting 216 answers were correct. This overwhelmingly confirms that even though the contrast of the text was not always very high, the text was always readable for participants both in terms of size and contrast. This shows that our system reliably demonstrated the required functionality, such as switching views between different interaction zones and adapting the text size.

After each tested condition participants were asked to explicitly confirm the behaviour of the systems from their perspective (for example "How many interaction zones did you notice?"). All participants successfully observed all three different interaction zones (including changes in colour of text) in the ACTIVE condition. In the PASSIVE condition all participants except one only saw a single interaction zone. However, even this participant only noticed a faint shadow of one of the other interaction zones and was unable to make out any of the text. This confirms the proxemic multi-view system was usable in all three interaction zones.

Finally, for the question *Do you consider this type of a dynamic dual view system useful?* (1 = Completely Useless, 7 = Very useful) the median rating was 5. For the question *Would you use this system if it were installed at a real train station?* (1 = Definitely Yes, 7 = Definitely No) the median rating was 5.5.

7. SCENARIO 2: VIDEO

The use of subtitles can be crucial as they enable people that would otherwise have trouble following the movie to fully enjoy the experience. However, the presence of subtitles can have adverse effects on the rest of the group by potentially causing a shift in attention and creating distractions. In foreign language teaching, studies such as that by Lafiti et al. [12] suggest that subtitles improve listening comprehension. However, Taylor [16] found evidence that the added cognitive processing strain of reading subtitles can have a negative influence on some groups of foreign language students. We created a system, which has the ability to show a video clip including subtitles to one part of the audience,

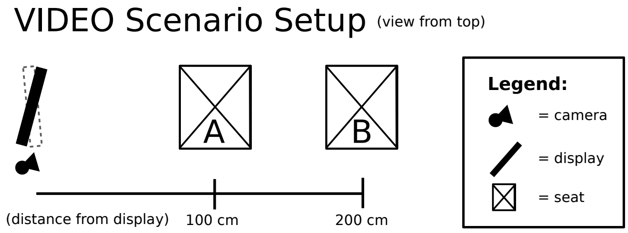


Figure 5. A diagram of the setup for the Video scenario. The display was tilted in different directions for each condition (dotted outline) to simulate a living room setup.

while only showing the video to everyone else. In addition, the system can also dynamically modify the font size of the subtitles depending on the distance of the viewers. This results in a multi-user, multi-view distance-sensitive movie experience.

7.1 Procedure

The physical setup of the VIDEO scenario is shown in Figure 5. Two seats arranged in two rows were used. In the PASSIVE condition, participants were seated on seat B and the display was swivelled so that they would be looking at it at a 20° angle horizontally to the right from their point of view (see Figure 5). This angle was used to hide any subtitles without affecting the colour accuracy of the video much (effectively the primary view of the multi-view display). In the ACTIVE condition, the participants were initially seated on seat A and the display was swivelled 20° horizontally to the left from their point of view (see Fig. 5 for reference).

The VIDEO scenario used the same protocol as the TRAIN scenario, consisting of an introduction to the primary task, performance of the primary task and filling out an answer sheet to gather performance related measures. In both conditions (ACTIVE, PASSIVE), the participants were instructed to answer a number of questions about the content in the video (six questions in each of the two conditions). These questions were not provided to participants right away but appeared on the screen while the video was playing. Questions related to what was happening in the video at the times they were shown. The participants were also instructed to answer questions in a black colour pen. The reason for these differences was that apart from the questions (as in PASSIVE), they were expected to see subtitles under the video as well as a set of instructions complementing the questions shown above the video. Instructions included changing the seat to one closer or farther from the display, switching the colour of the pen when answering questions, and raising their hand to alert the experimenter.

After completing the primary task for one of the conditions, participants were asked to fill out a questionnaire verifying the secondary measures (e.g. visibility of subtitles). After completing the tasks for both the ACTIVE and PASSIVE conditions they were administered a final questionnaire soliciting their opinions about the system.

7.2 Results

Again, we examined the correctness of the answers to the factual questions the participants were presented with (e.g. "What is the name of the dragon?"). Participants were asked 6 questions per condition. Additional data points were gathered about whether or not the participants followed the on-screen instructions in the ACTIVE condition. With the exceptions of one participant putting one of their answers in the wrong place and answering another question wrong, and another participant consistently mistaking their left side for their right (three questions altogether), every question was answered correctly. As with the TRAIN scenario this confirms that users were always able to accurately read the text.

The answers to the secondary measures confirmed the functional behaviour of the systems from the participants' perspective (for example "Did you notice any subtitles?"). Unexpectedly, one out of the 18 participants was able to notice the subtitles in the PASSIVE condition, but even then only faintly. In the ACTIVE condition, all the participants were able to see and read the subtitles (and reacted to all text-based instructions). This confirms the expected behaviour of the system.

Finally, for the question *Do you consider this type of a dynamic dual view system useful?* (1 = Completely Useless, 7 = Very useful) the median rating was 6. For the question *Would you use this system at home?* (1 = Definitely Yes, 7 = Definitely No) the median rating was 5.

8. DISCUSSION

The two user studies verified that it is possible to design multi-view proxemic systems using commodity hardware and software. As a first study of the first multi-view proxemic systems implemented, our studies confirm that the systems provide sufficiently accurate information for users to solve a set of routine tasks using them. Users also report that they find such systems useful and would use them if they were available. After testing the two systems participants were invited to provide comments about the systems and the technologies. Comments were generally enthusiastic. Some representative comments are included below:

VIDEO scenario: *"Clever! I like the way it works towards an inclusive solution, not an exclusive one."* (Participant P18), *"I think it's a really good idea, especially for cinemas. I found the screen without the subtitles for me better because I found the subtitles distracting."* (P17), and *"It would be helpful if one person was hard of hearing as they could see the subtitles without distracting other people watching."* (P01).

TRAIN scenario: *"It is a good idea because if you are running into a station you can see basic info from a distance & as you get closer to the signs/platforms you then get the detailed info that you need."* (P11).

However, while our application prototypes successfully fulfilled all their requirements, there are a number of points to be considered by designers of rich proxemic applications using viewing angles and multi-view displays.

On the technological front, we advise designers to use a different multi-view technology if multiplexing of different views is necessary. We found that the colour compression method [9, 11] worked very well for the VIDEO scenario, which had no need to multiplex different views to generate the distinct simultaneous views. Using this method to create subtle interfaces that only aim to restrict the visibility of some of the information present has a lot of potential. However, in the TRAIN scenario, the interaction between the colours led to textual views that were not very aesthetically pleasing. For scenarios such as these, we recommend using alternative technologies not based on colour manipulation, such as lenticular sheets. Additionally, the colour manipulation-based method [9, 11] only allow separate simultaneous views along a single axis. Using lenticular sheets potentially allows generating simultaneous distinct views along both the horizontal and vertical axes.

The distance-sensing method we used performed very well but there is room for improvement. The computer vision-based system is dependent on the resolution of the camera for increasing its maximum detection range. Additionally, as the camera resolution increases, the algorithm has to process exponentially more data. This places computational constraints on the system, which has to keep up the image processing rate for the system to be responsive. To rectify this, we have proposed a solution based on sensor fusion between a Kinect and our computer vision algorithm [5].

9. CONCLUSIONS

This paper extends the existing body of knowledge in proxemic interaction by expanding the notion of proxemics by proposing the inclusion of the horizontal and vertical angles of view as important parameters for proxemic interaction. By considering the position of a person in all three dimensions, we define a richer interaction space, which enables novel types of collaboration and personalisation of interaction surfaces, especially for multi-display environments. We also introduce the notion of multi-view proxemics and demonstrate how to build working systems using commodity hardware and software. We sample the application space with examples of potential uses of this approach and further detail and validate two realistic application scenarios.

Our results indicate that our multi-view, multi-user distance sensitive interactive systems have been realised and operate as expected. The very accurate answers from our 18 participants indicate that both the distance and viewpoint sensitive aspects of the interaction support delivery of information as expected. Further, the interaction zones can easily be discovered and were explored by all participants to answer questions. Importantly, we expect actual use of such systems to come from scenarios with multiple users, with distinct views for distinct distances being generated simultaneously at different angles. In addition, distance measurement is not always required for all interaction zones. The static zone in the TRAIN scenario can operate without tracking eye pairs, while the close and medium zones will have the required tracking data to deliver dynamic, distance-sensitive information and updates. Support for both types of interaction zones is a positive feature of our approach. This is emphasised by our validation of the example systems and people's positive experiences.

10. ACKNOWLEDGEMENTS

This work was supported by the Engineering and Physical Sciences Research Council (grant number EP/H027408/1) and the Scottish Informatics and Computer Science Alliance.

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