Evaluating layout discrimination capabilities of continuous and discrete automultiscopic displays

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Abstract

Continuous automultiscopic displays represent a promising technology, able to drive users into really involving and compelling experiences. In this paper, we report on perceptual experiments carried out to evaluate the depth discrimination capabilities of this technology with respect to two-view (stereo) and discrete multi-view designs. The evaluation employed a large scale multi-projector 3D display offering continuous horizontal parallax in a room size workspace. Two tests were considered in the context of depth oblivious rendering technique: a layout discrimination task, and a path tracing task. Our results confirm that continuous multiview technology is able to elicit depth cues more efficiently with respect to standard stereo system, providing clear advantages in typical analysis tasks like network structures understanding. Furthermore, our results indicate that depth perception capabilities are closely related to the number of views provided by multiview systems.

1. Introduction

Automultiscopic displays offer to multiple eye-naked viewers the possibility of viewing high-resolution stereoscopic images from different positions. These displays are composed of a set of view-dependent pixels which reveal different colours to the observer based on the viewing angle [18]. Autostereoscopic displays are the simplest embodiment of this technology, and have already reached the mass market. Since only two images are presented, no parallax effects are achieved during ego-motion. Discrete multiview displays are an evolution of this technology, typically based on optical masks, lenticular lenses, or integral lens sheets. A classic review of this subject can be found in [7]. A typical example is [12] large scale projection-based 3D display prototype consisting of 16 1024x768 projectors and lenticular screens. A number of manufacturers (such as Philips, Sanyo, Sharp, Samsung, Stereographics, Zeiss) produce monitors based on variations of this technology. These displays typically use 8–10 images at the expense of resolution. A 3D stereo effect is obtained when left and right eyes see different but matching information. The small number of views produce, however, cross-talks and discontinuities upon viewer motion. Recently, continuous multiview (light field) displays have been demonstrated [1], and strive to present a virtually continuous image to multiple freely moving viewers in a large workspace. To achieve this goal, they exploit a specially arranged array of projectors and a holographically recorded screen, which provides combined view selection and blending, leading to a homogeneous light distribution and continuous 3D view with no visible crosstalk within the field of depth determined by the angular resolution. These displays provide extremely compelling 3D images [3]. A large computational effort is, however, required to generate a large number of light beams of appropriate origin, direction, and colour.

The goal of this paper is to verify whether the greater complexity of continuous multiview systems is worthwhile also from a perceptual point of view, when compared to stereo or discrete multiview displays. We consider, in particular, situations that are common in a medical setting, which is one of the most important application domains for this technology. Specifically, clinicians are typically faced with the need to interpret cluttered images generated by volumetric techniques. To this end, various order-independent techniques have been proposed to emphasise anatomical structures [5], and it has already been shown that volumetric understanding can be improved by presenting results on displays eliciting more depth cues than conventional 2D monitors [13, 4, 3].

Instead in this paper, we report on preliminary results of a series of perceptual evaluation tests aimed to compare the depth discrimination capabilities of discrete and continuous multiview systems. A large scale multi-projector light field display offering continuous horizontal parallax in a room-size workspace was employed and two tests were considered to simulate typical depth-oblivious rendering strategies: a layout discrimination test, and a path tracing test. Our results indicate that continuous multiview technology is able to elicit depth cues more efficiently with respect to standard stereo and discrete multiview systems, providing clear advantages in typical analysis tasks like network structures understanding. The rest of the paper is organised as follows: section 2 provides an overview of related work, while section 3 describes the multiview technology considered and section 4 the experimental setup employed during the evaluation. Finally, sections 5 and 6 contain results of our perceptual evaluation, and section 7 points out our concluding remarks.

2. Related work

Our work share some common points with other groups who worked on the perceptual evaluation of autostereoscopic display systems, depth oblivious volume rendering techniques or in the context of network structures interpretation. Specifically, Kersten and others [11] focused on the effects of stereopsis and simulated aerial perspective on depth perception in translucent volumes. Boucheny and others [4] considered a perceptive evaluation of volume rendering techniques, demonstrating that static images are confusing, while dynamic cues, such as motion parallax, provide relevant information to disambiguate depth perception. Similarly to them, we considered a depth oblivious volume rendering technique, but our target was to demonstrate that continuous parallax light field technology provides natural cues that enable users to easily perceive depths and layouts more efficiently with respect to discrete multiview systems. In particular, we intend to elucidate which is the effect of the number of views on the depth perception, similarly to what was proposed by Dodgson [6]. In that work, Dodgson analysed the capabilities of different autostereoscopic displays in relation to the viewing zone, considering it as the window of the viewing space where only a single view is visible at a time. Grossman and Balakrishnan [8] addressed the problem of evaluating the depth perception in the particular case of volumetric displays. The methodology they employed is similar to ours, but, due to hardware limitations of their display system, specially those regarding the size and resolution of produced images, users are not able to understand complex scenes. Finally, we carried out some performance tests related to the interpretation of network structures, similar to those performed by Ware and others [15] to demonstrate that high resolution stereo displays improve graph comprehension. In our case, the employed tests were to prove that continuous parallax provided by light field technology gives advantages with respect to standard stereo systems.

3. Multiview displays technology

The performance and characteristics of multiview display systems vary upon different factors, such as the number of images per frame, the technology employed for generating the light beams, its resolution in pixels, the geometry size and so on. In this context, since we are focused in studying depth discrimination capabilities, we classify the different multiview display systems with respect to the number of views considered:

- Continuous multiview display systems: they are characterised by the generation of a large number of views which can be blended thanks to the use of a specially recorded screen surface. In this way they provide a smooth and continuous transition between different views.
- Discrete multiview display systems: they provide a small number of separate views, typically because the screen surface can cause a light loss, visible barriers, and dark zones between the different viewing slots, generating banding artifacts and discontinuities upon the viewer motion.

3.1. High-res continuous multiview technology

The continuous multiview display system considered in this work is based on projection technology and uses a specially arranged projector array controlled by a PC cluster and a holographic screen. It is based on patents held by Holografika (`www.holografika.com`), who has developed the display hardware.

The projectors are densely arranged at a fixed constant distance from a curved (cylindrical section) screen. The projectors are used to generate an array of pixels of controlled intensity and colour onto the holographic screen. Each point of the holographic screen then transmits different coloured light beams in different directions in front of the screen (see Fig. 1). Mirrors positioned at the side of the display reflect back onto the screen the light beams that would otherwise be lost, thus creating virtual projectors that increase the display field of view. The screen is the key element in this design, as it is the optical element enabling selective directional transmission of light beams. It is a holographically recorded, randomised surface relief structure that enables high transmission efficiency and controlled angular distribution profile. The horizontal light diffusion characteristic of the screen is the critical parameter influencing the angular resolution of the system, which is very precisely set in accordance with the system geometry. The angular light distribution profile introduced by the screen, with a wide plateau and steep Gaussian slopes precisely overlapped in a narrow region, results in a highly selective, low scatter hat-shaped diffuse characteristic. The result is a homogeneous light distribution and continuous 3D view with no visible crosstalk within the field of depth determined by the angular resolution (see figure 1). The screen acts as a special asymmetrical diffuser and with proper software control, the light beams leaving the various pixels can be made to propagate in specific directions, as if they were emitted from physical objects at fixed spatial locations.

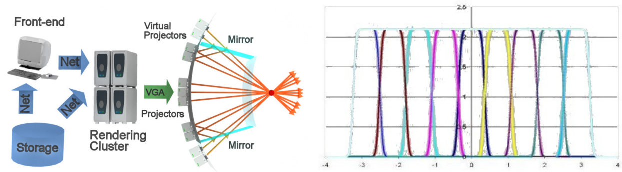

Figure 1: ***Display concept.*** *Left: the display is driven by a rendering cluster controlling a projector array. Each projector emits light beams toward a subset of the points of the holographic screen. Side mirrors increase the available light beams count. A large number of light beams can create a spatial point. Right: the screen introduces a light distribution profile characterised by a wide plateau and steep Gaussian slopes precisely overlapped in a narrow region, resulting in a continuous 3D view.*

3.2. Projecting geometry with horizontal parallax

The image generation methods for continuous light field displays must take into account the display characteristics in terms of both geometry and resolution of the reproduced light fields. Following [10, 3], a multiple-center-of-projection technique is employed for providing images with good stereo and continuous horizontal parallax cues. In order to derive geometry transformation needed to project points to the screen, physical properties of the screen are considered. We assume that the screen is centred at the origin with the y axis in the vertical direction, the x axis pointing to the right, and the z axis pointing out of the screen. Given a virtual observer at $\mathbf{V}$, the ray origin for a given screen point Q is then determined by

$$O = (Q_x - E_x, V_y, V_z) \tag{1}$$

where E_x is the horizontal position of the currently considered projector. The solution is exact for all viewers at the same height and distance from the screen as the virtual observer and proves in practise to be a good approximation for all other viewing positions in the display workspace.

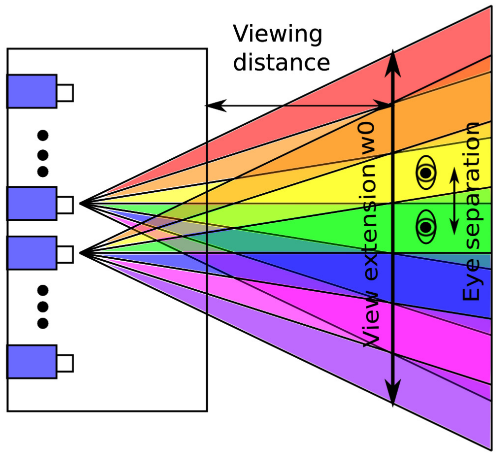

Figure 2: ***Discrete multiview scheme.*** *the general discrete multiview with parameters related to equation 4: each zone is represented by a different colour, inner zones are shared among different projectors [6].*

3.3. Display configurations

The target of this evaluation work is to compare continuous and discrete multiview display technologies with reference to depth discrimination cues involved by display geometry differences. To simulate discrete designs it is possible to conceptually divide the user viewing space into a finite number of windows, called viewing zones, in each of which only a single image is visible, while still retaining both stereo and movement parallax cues. To this end, the multiple-center-of-projection equation can be simplified by reducing the number of views provided. Referring to equation (1), the ray origin can be corrected according to the geometry design of the display to be simulated. For example, considering a standard stereo display, only two views have to be generated and the ray origin abscissa of equation 1 needs to be corrected in the following way:

$$O_x = \begin{cases} -\delta & \text{if } O_x < 0 \\ +\delta & \text{if } O_x > 0 \end{cases} \tag{2}$$

where δ is the average half interpupillar distance (about 35 mm). In the same way, by adequate quantisation of the observer space, the correction can be applied to simulate generic discrete multiview designs. Considering N not overlapping viewing zones having center γ_i and width ρ_i, the correction equation is the following:

$$O_x = \begin{cases} \gamma_0 & \text{if } O_x < \gamma_0 + \rho_0 \\ \gamma_i & \text{if } |O_x - \gamma_i| < \rho_i \\ \gamma_{N-1} & \text{if } O_x > \gamma_{N-1} - \rho_{N-1} \end{cases} \tag{3}$$

As indicated by Dodgson [6] the viewing zone widths ρ_i at the viewing distance should be less than the interpupillar distance σ so that in each position the two eyes can perceive two different images, thus producing the stereoscopic effect (see figure 2). If we have N views which subtend an extension w_o the previous relation can be expressed as

$$w_o < N \times \sigma \quad (4)$$

If inequality is not satisfied there will be some zones where users lose depth perception, because both eyes are hit by the same image. Thus, in a normal usage of multiview system, users stay at fixed positions instead of exploiting parallax by ego-motion, and tend to avoid to interfere with zones where the stereoscopic effect is unstable, thus producing annoying artifacts. As we can see in figure 2, each projector splits its image in a certain number of viewing zones, highlighted here with different colours. In areas where different colours interfere, users perceive a wrong image, while at the correct viewing distance, images match correctly without introducing any unwanted interference.

4. Experimental setup

Hardware setup The large scale continuous multiview display employed for tests can visualise 35MPixels by composing images generated by 72 SVGA LED commodity projectors illuminating a 160×90cm holographic screen. The display provides continuous horizontal parallax within an approximately $50°$ horizontal field-of-view, with $0.8°$ angular accuracy. The pixel size on the screen surface is 1.5mm. The same continuous multiview system is customised to simulate discrete systems by employing the observer space discretization described in section 3. In this work, we evaluated various discrete multiview configurations obtained by increasing the view width between adjacent views, in order to verify whether this factor influences depth perception capabilities.

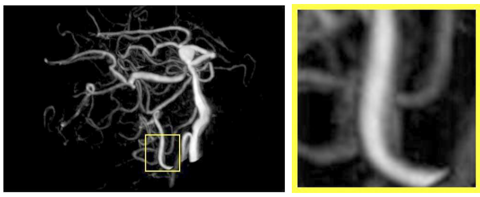

Figure 3: ***Depth oblivious MIP angiography rendering.*** *MIP volume rendering of a rotational angiography scan of a head with aneurysm. The positions and the crossings of vascular structures are not detectable, or wrongly interpreted.*

Rendering techniques With respect to the image generation, we focused on a order-independent rendering context, i.e., on depth-oblivious techniques that do not provide occlusion cues. Such techniques are frequently found in medicine, Maximum Intensity Projection (MIP) being the most common one. It is a simple variant of direct volume rendering, where, instead of composing optical properties, the maximum value encountered along a ray is used to determine the colour of the corresponding pixel [14]. MIP is considered very useful for displaying structures that have attenuation higher than those in the neighbourhood, such as contrast enhanced vessels and ureters, and it is thus the option of choice for CT angiography and CT urography. However, it does not provide depth information, and, thus, in normal 2D displays users cannot reliably detect the 3D relationships of depicted structures. As a matter of example, we can consider the analysis of a rotational angiography scan of a head with aneurysm (Fig. 3). In a 2D view, the positions and the crossings of vascular structures can be wrongly interpreted. For instance, in figure 3 we can see two crossing blood vessels, with the one at the front having an intensity less than the one at the back. From this point of view, the back one is visible at the intersection and hides the front vessel because of its higher intensity, providing a wrong impression. It has already been shown that understanding can be improved by presenting results on displays eliciting more depth cues than conventional 2D monitors [13, 4, 2]. Instead, in this paper, the questions we are considering are: *Is continuous multiview technology able to provide depth cues needed for layout discrimination in the context of order independent rendering? What are, if any, the differences with respect to standard disparity-based stereo systems? Is the viewing space discretization a critical factor for depth discrimination? Does continuous parallax provide advantages for typical spatial understanding tasks?* To answer these questions, we carried out a series of evaluation tests employing order-independent rendering: a typical layout discrimination perceptual test, with stimuli containing various confusing perceptual hints, and a path tracing performance test, to measure how much horizontal parallax provided by continuous multiview displays helps in the context of the interpretation of tree structures.

5. Depth discrimination evaluation

5.1. Stereo vs Horizontal parallax

We first evaluated the motion parallax effect provided by continuous multiview technology with respect to depth discrimination. We proved that this technology is more effective in eliciting depth cues than stereoscopic displays, especially in conjunction with depth-oblivious techniques, such as maximum intensity accumulation. We verified this assertion by carrying out a series of psycho-physical tests. We used a typical 2 forced-choice (2FC) psycho-physical discrimination task, where 10 pre-screened subjects were

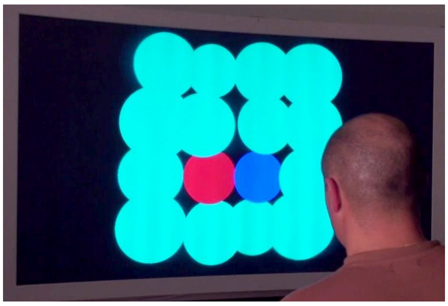

Figure 4: ***Disks discrimination test.*** *Subjects were asked to discriminate in depth between two disks, red and blue, partially overlapping and symmetrically displaced with respect to the screen. Maximum intensity is employed to provide confusing false occlusion.*

asked to indicate the closest one between two partially overlapping disks, rendered in red and blue (Fig. 4). Viewers were located at 120cm from the screen. For a given trial, the two disks were assigned a depth of $\pm D$ with respect to the screen plane and placed amid other disks at varying depths. The entire scene was rendered using maximum intensity projection, with intensity unknown to the viewers. Other confusing hints were added in order to eliminate potential biases coming from other cues: relative sizes, false occlusions and colours. We first performed the tests using two different display configurations: a two-view stereoscopic setting and a full continuous horizontal parallax setting. All the display configurations were obtained with the large scale display by suitably constraining the virtual observer position (see Subsec. 3.2).

Results We report on statistical analysis of hit rates obtained by 10 subjects for the considered depth distances and viewing conditions. Table 1 contains numerical results for

D(mm)	Hit Rate(S)	Hit Rate(C)	p
5	0.53 ± 0.03	0.59 ± 0.03	0.17
10	0.55 ± 0.03	0.71 ± 0.02	< 0.001
20	0.67 ± 0.04	0.79 ± 0.02	0.02
50	0.81 ± 0.03	0.91 ± 0.02	0.09
100	0.95 ± 0.02	0.96 ± 0.02	0.55

Table 1: ***Statistical results for disk depth discrimination test.*** *The first column contains the depth differences considered, while the second and third contain mean hit rates scored by 10 subjects over 10 trials with disparity based stereo (S) and continuous multiview horizontal parallax (C). Last column contains the results of ANOVA with respect to the viewing condition.*

five depth differences and two viewing conditions. Specifically, first column contains the depth differences considered, while the second and third contain mean hit rates together with standard errors scored by the 10 subjects over 10 trials with disparity based stereo (S) and continuous multiview horizontal parallax (C). Last column instead contains results of analysis of variance with reference to the viewing condition. ANOVA clearly shows that there is no significant effect of viewing condition for depth differences 5mm and 100mm ($p > 0.1$), while a main effect is experienced for depth differences 10mm, 20mm and 50mm ($p < 0.1$). This fact, together with the mean hit rates values, suggests us the main depth ranges for discrimination: above 50 mm stimuli are almost perfectly recognisable for each viewing condition, under 10 mm stimuli cannot be recognised for each viewing condition. In the range between 10 mm and 50 mm, there is difference between disparity based stereo and continuous parallax, suggesting that with continuous parallax the JND (just noticeable difference) is smaller.

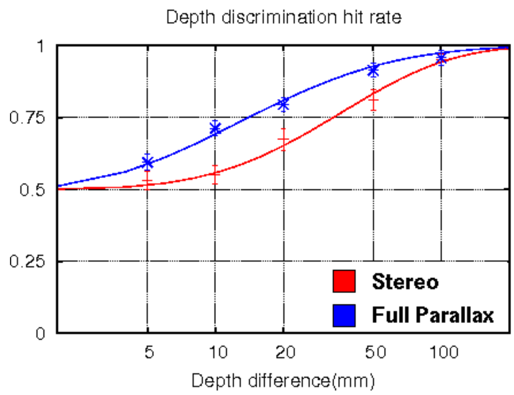

Figure 5: ***Stereo vs Parallax Disks discrimination results.*** *Hit rates (standard error bars and psychometric fit) obtained with stereo and full parallax display configuration.*

Fig. 5 shows mean hit rates and standard error bars on a logarithmic scale, together with the psychometric function fits obtained by employing the psignifit package [16, 17]. The psychometric function fits were obtained by considering the following function:

$$\Psi(x; \alpha, \beta, \gamma, \lambda) = \gamma + (1 - \gamma - \lambda)F(x; \alpha, \beta) \quad (5)$$

where γ gives the lower bound of Ψ, and can be interpreted as the base rate of performance in the absence of a signal, while λ is the upper bound of the psychometric function representing a reflection of the rate at which observers lapse, responding incorrectly regardless of stimulus intensity. In the case of depth discrimination tasks, the Weibull distribution was employed:

$$F(x; \alpha, \beta) = exp(-(\frac{x}{\alpha})^{\beta}). \quad (6)$$

The psychometric functions represented in figure 5 were obtained by considering as stimulus value $x = ln(D)$. Considering statistical results and psychometric function fits obtained with the disk discrimination test, it appears evident that continuous multiview provide a better discrimination with respect to binocular stereo viewing. Threshold levels are significantly different ($\Psi_C^-1(0.75) = 14mm < \Psi_S^-1(0.75) = 32mm$), clearly showing a sensible perceptive improvement for continuous multiview.

5.2. Evaluating discrete multiview designs

After showing that continuous parallax is a decisive factor for depth discrimination, we focused on the analysis of discrete multiview designs. These can be obtained by reducing the number of views in two ways: first, by reducing the working zone width w_o (see equation (4)), resulting in a reduction of the field of view. In this case, image quality is preserved and depth cues are maintained with the cost of a limited working zone. However, in this way the potential of multiview technology is reduced, since the display can be used by a limited number of users. The other method for reducing the number of views consists instead of maintaining the full field of view and increasing the distance ρ between adjacent views (see equation (3)). We evaluated the depth discrimination capabilities of the multiview technology with respect to this factor, by considering a typical scenario of a user positioned at distance $Z = 1200mm$ and observing a scene centered at $D = 100mm$ from the screen. Three different viewing widths were considered: $\rho = 60mm$ corresponding to 12 views, $\rho = 30mm$ corresponding to 24 views and $\rho = 10mm$ corresponding to 72 views, the last one being equal to the maximum angular resolution obtainable with the light field display considered.

Qualitative evaluation We first carried out a qualitative evaluation in order to prove that a limited number of views degrades the image quality thus resulting in annoying artifacts. In a preliminary analysis of a scene with a depth complexity of $D = 100mm$ (we employed the same scene employed for depth discrimination task with an offset of D along z direction), 10 subjects were asked to indicate if transition artifacts were perceived during motion, for the three view widths considered. All subjects experienced annoying artifacts for $\rho = 60mm$, the same artifacts dramatically reducing when $\rho = 30mm$. This fact suggests that $\rho = 30mm$, corresponding to about half the interpupillar distance, is the inferior limit for a discrete system that is supposed to provide a compelling 3D experience, and a smooth transition between views during motion.

Perceptual evaluation Once assumed that image quality depends on the number of views employed, we carried out a perceptual analysis to evaluate whether a limited number of views degrades also the depth discrimination performance, or whether horizontal parallax cue is correctly provided even with a reduced number of views. To this end, we considered the same disk discrimination test employed in subsection 5.1. The same 10 subjects were asked to discriminate the depth of the two coloured disks for the three view width configurations ($\rho = 60mm$, $\rho = 30mm$, and $\rho = 10mm$)

$\rho(mm)$	D(mm)	Hit Rate $\pm$ **SE**
60	100	0.93 ± 0.03
	50	0.76 ± 0.05
	20	0.71 ± 0.04
	10	0.54 ± 0.04
30	100	0.93 ± 0.02
	50	0.88 ± 0.04
	20	0.72 ± 0.05
	10	0.57 ± 0.08
10	100	0.93 ± 0.04
	50	0.9 ± 0.04
	20	0.81 ± 0.06
	10	0.7 ± 0.05

Table 2: ***Statistical results for disk depth discrimination test: comparison of three different multiview configurations.*** *The first column contains the multiview configurations considered, while the second column contains the depth differences employed and the third column contains the mean hit rates scored by 10 subjects over 10 trials together with standard errors.*

Results Table 2 summarises numerical results of hit rates obtained by the subjects for four different depth differences and the three different viewing conditions:$\rho = 60mm$, $\rho = 30mm$, and $\rho = 10mm$. As expected, results obtained for $\rho = 10mm$ are very similar of those obtained during first perceptual test in the case of full horizontal parallax (see table 1). Furthermore, it appears evident that starting from disk depth differences below 50 mm, error rates for $\rho = 60mm$ are considerably higher with respect to the other viewing conditions, while from depth differences below 20 mm, error rates for $\rho = 30mm$ are considerably higher with respect to those obtained with $\rho = 10mm$. This clearly shows that the number of views effects the depth discrimination capabilities of the system. An ANOVA with respect to the viewing condition was also performed and indicated that there is a main effect for depth differences under 50 mm. In order to highlight whether hit rates obtained with the different view conditions are statistically different, a Tukey post-hoc test was also performed, revealing a significant difference between view width $\rho = 30mm$ and $\rho = 10mm$ for depth differences below 20 mm ($p < 0.01$).

Finally, figure 6 represents the hit rates with error bars on a

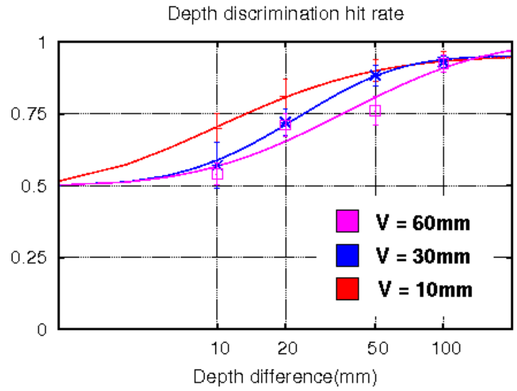

Figure 6: ***Discrete multiview depth discrimination results.*** *Hit rates (standard error bars and psychometric fit) obtained with different discrete multiview configurations:* $\rho = 60mm$, $\rho = 30mm$ *and* $\rho = 10mm$.

logarithmic scale, together with the psychometric function fits obtained by employing the psignifit package [16, 17]. Fits were obtained considering a Weibull distribution, with $x = ln(D)$. Threshold levels are significantly different ($\Psi^-1(0.75) = 13.4mm$ for $\rho = 10mm$, $\Psi^-1(0.75) = 24.2mm$ for $\rho = 30mm$, and $\Psi^-1(0.75) = 35.4mm$ for $\rho = 60mm$), clearly indicating that the number of views dramatically effects depth discrimination capabilities.

6. Performance evaluation

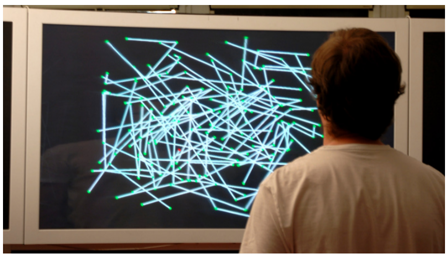

Figure 7: ***Path tracing test.*** *Subjects were asked to find paths marked by red ends and to indicate whether they are composed by two or three segments. Maximum intensity is employed to provide confusing false occlusion.*

Another way to quantify the performance of multiview technologies consists of investigating whether it improves the understanding of network structures.

Description To this end, we considered a perceptual test where users were asked to trace complex paths. Specifically, 10 subjects observed a scene composed by a number of white polylines paths randomly placed, each one containing a number of segments connected by green colour spheres (see figure 7). The paths were rendered employing maximum intensity projection, with random intensity values. A 2FC design was considered, where subjects were requested to find the only polyline having red dots at their ends, and to count how many segments it contained (two or three). The following conditions were considered: four scene complexities ranging from 100 to 1000 nodes, and two display settings (continuous multiview, and disparity-based stereo). Graphs were generated without layout optimisation, with consequent difficulties for interpretation. Only geometric constraints were considered as to force segments lengths inside the range $[0.05, 0.5]\frac{d}{l}$, where d is the scene bounding box diagonal, and l is the number of segments for a given path.

N	Hit Rate (S)	Hit Rate (C)	p
100	0.94 ± 0.03	0.96 ± 0.02	0.79
300	0.88 ± 0.04	0.95 ± 0.02	0.30
500	0.66 ± 0.05	0.89 ± 0.02	$< 10^{-3}$
1000	0.55 ± 0.04	0.78 ± 0.04	$< 10^{-3}$

Table 3: ***Statistical results for network interpretation performance test.*** *The first column contains the number of nodes in the graphs, while the second and third ones contain mean hit rates scored by 15 subjects over 10 trials with disparity based stereo (S), and continuous multiview horizontal parallax (C). Last column contains results of analysis of variance with respect to the viewing condition.*

Results Table 3 summarises numerical results of hit rates obtained by subjects for different graph sizes (in terms of number of nodes) and different viewing conditions: stereo(S), and continuous multiview(C). Even in results of this specific test it appears evident that continuous (C) multiview provides performance improvements in terms of mean hit rates with respect to binocular stereo (S). The ANOVA on viewing condition also highlights that hit rates are statistically different for graph sizes starting from 500 nodes, indicating that for graphs under 300 nodes interpretation is considered easy independently from viewing condition, while the effect of multiview is perceived for graphs having bigger size. It is interesting to note that with multiview technology, subjects are able to discriminate graphs with a number of nodes similar to those reported by Ware and others [15], even if our scenes were generated without considering any optimisation layout techniques [9]. Figure 8 plots hit rates together with error bars and psychometric function fits obtained with psignifit package [16, 17]. Even in this case, the stimulus value is the graph size expressed on a logarithmic scale $x = log(N_{max}) - log(N)$ where $N_{max} = 10000$, and the psychometric function is assumed to follow the Weibull distribution. Graphs clearly highlight how horizontal parallax cues provided by multi-

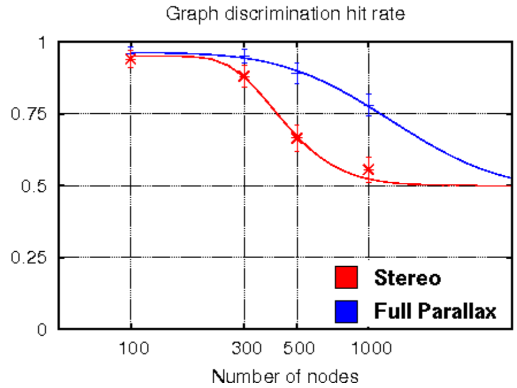

Figure 8: ***Graph understanding results.*** *Hit rates (standard error bars and psychometric fit) obtained with different display configurations: stereo and continuous multiview.*

view systems greatly help in graph understanding tasks.

7. Conclusions

Continuous multiview technology provides stereo and motion parallax cues in a way that supports natural 3D vision and easy collaboration between users. In this paper we reported on preliminary results of a series of evaluation tests aimed to compare the depth discrimination capabilities of discrete and continuous multiview systems. Depth discrimination tests indicate that parallax provides more depth cues, thus leading to a smaller just noticeable difference (JND) with respect to binocular stereo. However, further investigation is needed to find the precise JND, that we suspect to be related to the display characteristics (resolution and calibration), and to the observer distance. Furthermore, we compared performances for various discrete multiview designs. Our results indicate that the number of views effect the quality of experience as well as depth discrimination performances. As a conclusion, it seems that extremely egomotion is particularly helpful in path tracing tasks, and that this cue is delivered effectively by a continuous multiview design. As future work, we plan to perform an evaluation of the multiview technology in specific application contexts, such as diagnostic tasks or surgery planning in medicine.

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