TECHNICAL PAPER

Controlling Miniaturization in Stereoscopic 3D Imagery

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Viewers of stereoscopic three-dimensional (3D) imagery can perceive the absolute size of objects within a scene. On larger screens, the perceptual size of objects commonly appears bigger than reality, which matches viewers' expectations for big-screen, larger-than-life theatrical experiences. In contrast, the geometry involved in stereoscopic imaging can cause the perceptual size of objects to appear smaller than reality (miniaturization). Miniaturization can be distracting for viewers and is more extreme on smaller screens like 3D television and handheld 3D devices. A common misconception is that miniaturization occurs only when the stereo camera separation (interaxial) is larger than the human eye separation (interocular), or larger than 2.5 in. In this paper, counter examples of this misconception are provided, as well as an analytical framework that allows stereo camera operators to accurately predict what the miniaturization effect will be on any screen size. Example stereoscopic 3D images are shown to illustrate control of perceptual size.

Keywords: *stereoscopic, 3D, miniaturization, gigantism, size, perception, geometry*

INTRODUCTION

The use of stereoscopic three-dimensional (3D) imagery in motion picture and television (TV) content has the potential to enhance a viewer's suspension of disbelief and improve the impact of creative storytelling. During content's production and post-production, stereoscopic visual cues of depth and volume are often manipulated to achieve the creative vision. Increased amounts of stereoscopic depth often increase the visual intensity of the story, while less depth can lead to a more relaxed feeling.[1] In addition to depth, the stereoscopic volume cue, also called the roundness or shape ratio,[2] is commonly considered a creative parameter to manipulate. The stereoscopic size cue often gets less attention; thus, under certain conditions, a mismatch between an object's expected size and its perceived size can disrupt a viewer's suspension of disbelief and thus weaken the impact of the storytelling. This paper is about controlling the perception of size in stereoscopic 3D imagery.

PERCEPTION OF SIZE IN STEREOSCOPIC 3D IMAGERY

When viewing stereoscopic 3D imagery, viewers can perceive the absolute distance to images of objects. Comparing the distance to the object to the field of view (FOV) that is occupied by that object allows the viewer to perceive an absolute size cue that is not available in traditional two-dimensional (2D) monoscopic imaging. Consider **Figs. 1-3**, which show a ball occupying different amounts of FOV of a traditional 2D monoscopic image. The viewer's typical interpretation for the change in FOV of the image of the object in those figures is that the 50% FOV ball (**Fig. 3**) is

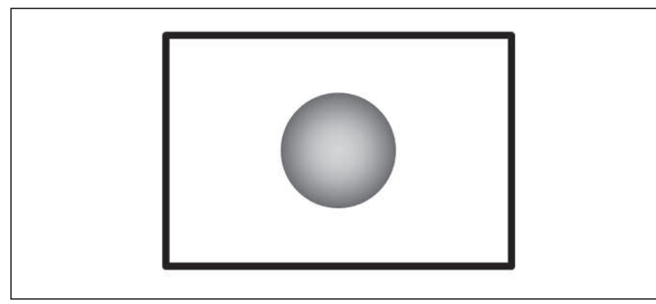

Figure 1. 30% FOV ball.

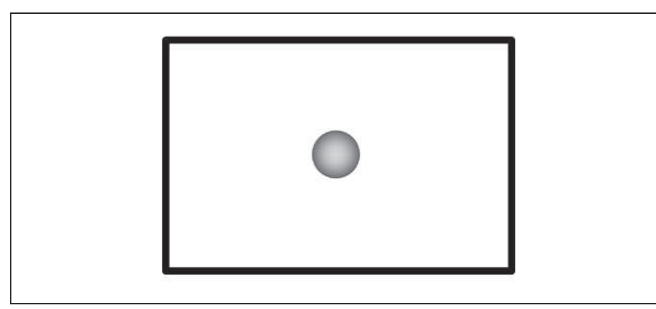

Figure 2. 10% FOV ball.

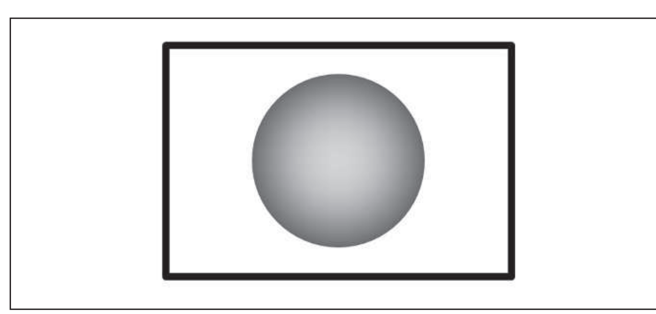

Figure 3. 50% FOV ball.

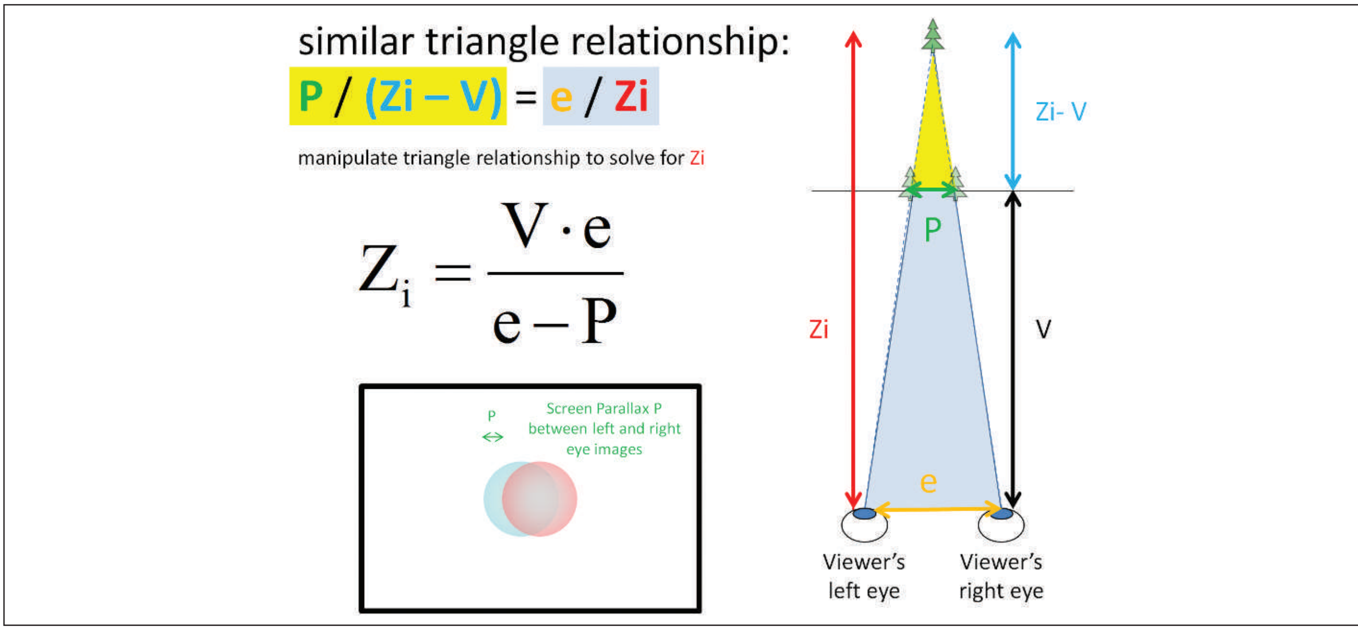

Figure 4. Similar triangles illustrating perception of stereoscopic image distance.

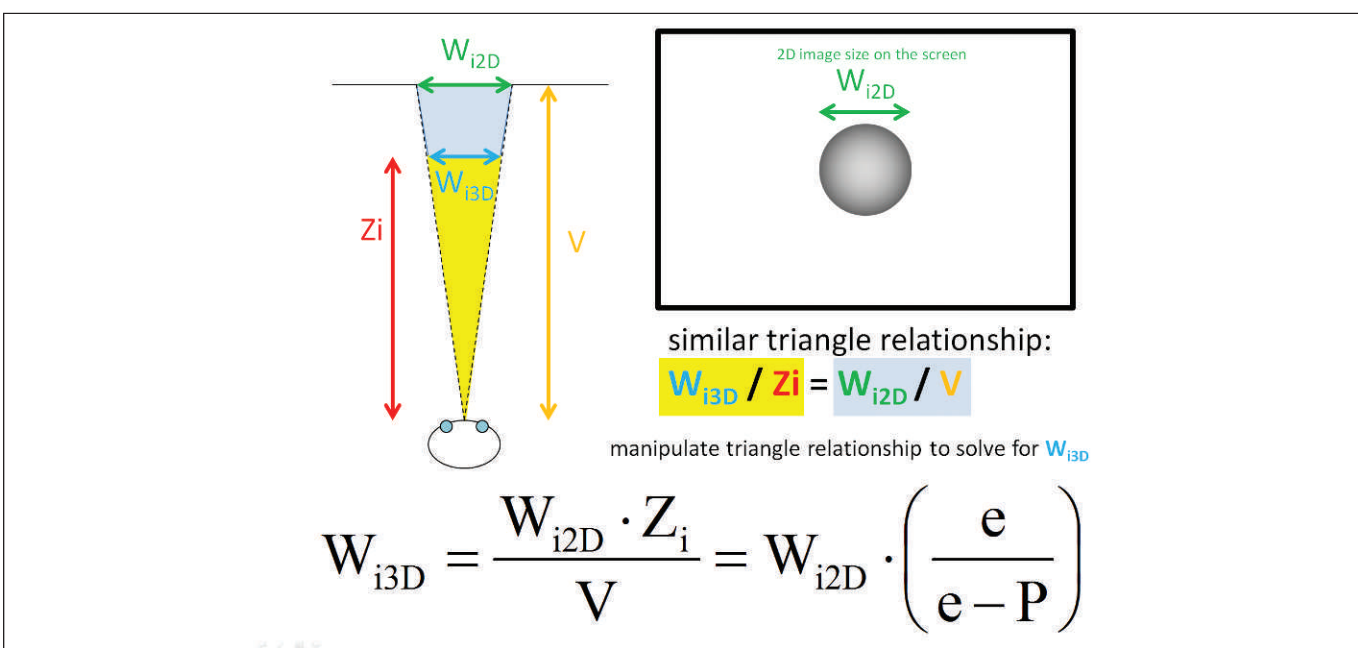

Figure 5. Similar triangles illustrating perception of stereoscopic image size.

closest to the camera, the 10% FOV ball (**Fig. 2**) is farthest from the camera, and the 30% FOV ball (**Fig. 1**) is at a distance between the 10% FOV ball and the 50% FOV ball.

Other possible interpretations of the three figures are usually ignored because 2D viewers assume that the size of an object is constant, regardless of its distance from the camera; therefore, relative changes in FOV typically give viewers cues to interpret the relative distance from the camera to the object when viewing 2D imagery.

Stereoscopic 3D imagery provides a direct depth cue that is absent in 2D imagery; thus, the viewer can interpret the distance to the

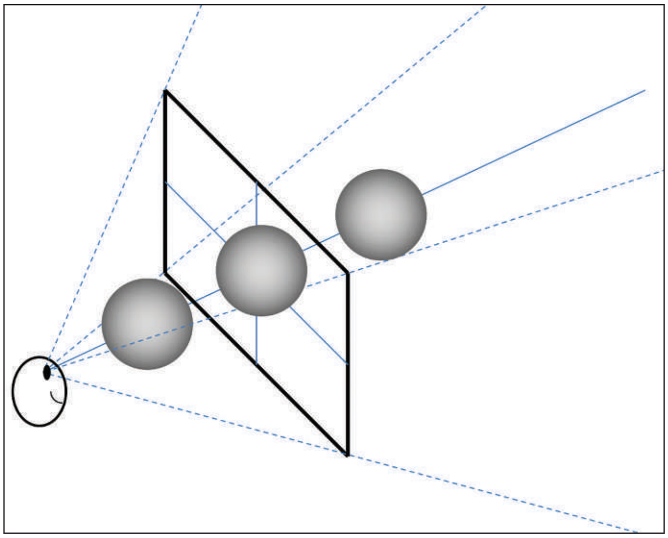

Figure 6. Example in which change in FOV matches change in distance.

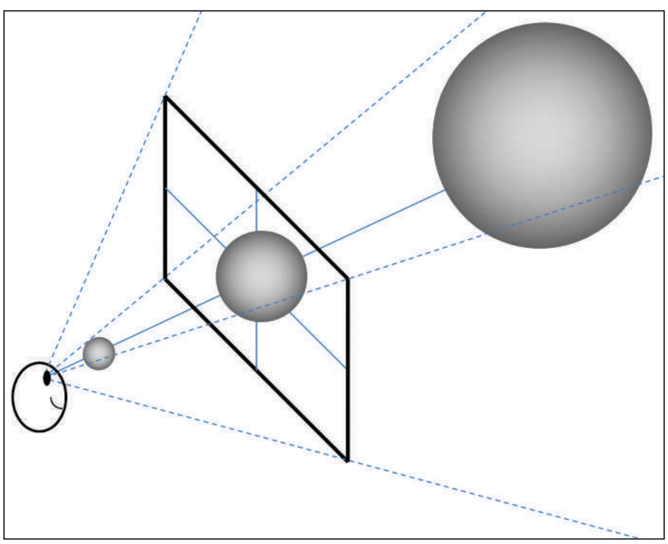

Figure 7. Example in which change in FOV is slower than change in distance.

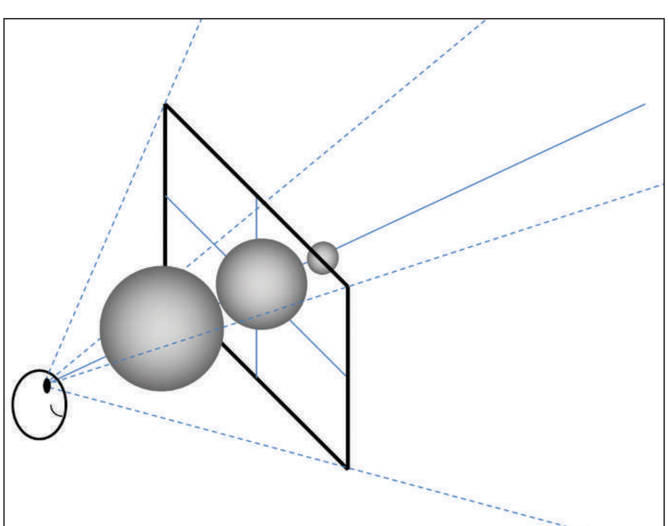

Figure 8. Example in which change of FOV is faster than change of distance.

object together with the FOV of the object to obtain an absolute size cue when viewing stereoscopic 3D images that is not possible when viewing the same images in 2D monoscopic imaging. **Figure 4** illustrates the well-known similar triangle geometric relationship among the screen parallax **P** of a 3D image on the screen, the viewer's interocular eye separation e, and the viewing distance **V** that is the basis of the perception of stereoscopic depth **Zi** in 3D imagery. **Figure 5** illustrates a simple, but not well-known, similar triangle relationship among the 2D image size $\mathbf{W}_{i2D}$ on the screen, the viewing distance **V**, and the perception of the stereoscopic depth **Zi** that is the basis of the perception of size $\mathbf{W}_{i3D}$ in 3D imagery.

The concept of the stereoscopic size cue can also be illustrated by viewing orthographic projections of the 3D perceptual viewing space frustum. **Figure 6** illustrates an example in which the change in distance to the image of the object matches the change in FOV of that object, which allows the viewer of the 3D image of the object to interpret that the object's size is the same regardless of its distance from the camera. **Figure 7** illustrates an example in which the change in distance to the object is faster than the change in FOV of that object, which can be interpreted as the object getting bigger as it moves away from the camera and getting smaller as it moves toward the camera. **Figure 8** illustrates an example in which the change in distance to the object is slower than the change in FOV of that object, which can be interpreted as the object getting smaller as it moves away from the camera and getting bigger as it moves toward the camera.

STEREOSCOPIC WIDTH MAGNIFICATION

The concepts described in the previous section about the viewer's perception of size through stereoscopic cues can be summarized by a mathematical factor called width magnification. Width magnification is determined by camera, set, and viewing parameters. When the width magnification factor for a particular object is greater than 1.0, the viewer perceives that the object is larger than it is in the real world, which is often called gigantism. When the width magnification factor for an object is less than 1.0, the viewer perceives that the object is smaller than it is in the real world, which is often called miniaturization.

The equation for width magnification shown was derived in other papers[2,3] and is appropriate for parallel stereo camera configurations, which are used throughout this paper. Similar equations can be established for toe-in stereo camera configurations. The equation is as follows:

$$Mw3d = (M*e*f)/(M*f*t - Zo*(2*M*h - e)) \quad (1)$$

where **M** is the magnification factor (the ratio between screen width **Ws** and camera sensor width **Wc**), **e** is the interocular distance (also known as the human eye separation—usually about 65 mm for adults), **f** is the camera lens focal length, **t** is the interaxial or camera separation, **h** is the horizontal image shift applied in the camera or equivalently in post-production to manipulate the convergence distance, and **Zo** is the object distance in front of the camera (the perpendicular distance between the object and the camera).

			Horizontal Image Shift Threshold Value per Eye		
Screen Size	Screen Width Ws (mm)	Magnification Factor M	e/(2M) (mm) for Super 35 Sensor	e/(2Ws) (% of Screen Width)	No. Pixels (1920 × 1080 Pixels)
23 in. diagonal	508	21	1.53	6.39	122.8
42 in. diagonal	928	39	0.84	3.50	67.2
55 in. diagonal	1215	51	0.64	2.67	51.3
65 in. diagonal	1436	60	0.54	2.26	43.4
10 ft. width	3048	127	0.26	1.07	20.5
20 ft. width	6096	254	0.13	0.53	10.2
40 ft. width	12,192	508	0.06	0.27	5.1

Table 1. Horizontal shift threshold values for different screen sizes.

The relative perceptual size of objects can also change depending on their distance from the camera. If there are multiple objects of the same size in front of the camera at different object distances **Zo**, their perceptual size may appear larger or smaller, depending on their position in z-space. The value of **h** determines whether the objects appear to get larger or smaller as they move away from the camera. If the value of h is greater than (**e**/2**M**), then objects appear to get larger as they move away from the camera, similar to what is shown in **Fig. 7**. If the value h is less than (**e**/2**M**), then objects appear to get smaller as they move away from the camera, similar to what is shown in **Fig. 8**. This means that for a given stereo image, the objects in that image may appear to have different relative sizes depending on the screen size used, because the value of **M** changes with different screen widths. In other words, the perception of the relative size of objects in a 3D image can be different when viewed on a larger theatrical screen from its appearance on a smaller 3DTV screen.

For example, a Super 35 camera sensor width **Wc** is approximately 24.0 mm; therefore, the corresponding magnification factor **M** for a 40 ft screen is (12,192 mm/24.0 mm) = 508. In contrast, the magnification factor **M** for a 65 in. diagonal 3DTV is (1436 mm/24.0 mm) = 59.8. The center column of **Table 1** shows the threshold horizontal shift (**e**/2**M**) values computed for different screen sizes using a sensor width of **Wc** = 24.0 mm. Comparing the actual horizontal shift used to produce the stereo images to the horizontal image shift threshold value in **Table 1** allows the production team to determine whether objects will appear to get bigger or smaller as they move away from the camera (which is called the width magnification trend later in this paper). **Table 1** also shows the threshold horizontal shift values in equivalent formats that may be more familiar to the production team, like percentage of screen width units per eye (**e**/2**Ws**) and number of pixel shift units per eye (assuming a 1920-pixel image width resolution).

Suppose the value of **h** is chosen to be 0.125 mm per eye (**h/Wc** = 0.125 mm/24.0 mm = 0.5% image width) for other creative reasons, perhaps because of volume- or depth-related choices.[1,4] Comparing the value of horizontal shift (0.5%) to the threshold values in **Table 1** allows the relative width magnification trend to be determined for this particular stereo image on different screen sizes. For example, the 0.5% shift is greater than **e**/2**Ws** = 0.27% on the 40 ft screen; therefore, the objects will appear to get bigger as they move away from the camera when shown on a 40 ft. screen (as illustrated in **Fig. 7**). If the same images with a 0.5% shift are shown on a 65 in. 3DTV, then the 0.5% shift value is less than the corresponding threshold value of (**e**/2**Ws**) = 2.26%; therefore, these same objects will appear to get smaller when they move away from the camera (as illustrated in **Fig. 8**).

EXAMPLE ILLUSTRATING STEREOSCOPIC WIDTH MAGNIFICATION

For a specific screen size and convergence distance, different camera settings can result in a horizontal shift value that is less than or greater than the threshold horizontal shift value for that screen size. This affects the relative width magnification trend for those images, as explained in the previous section. An example illustrates how different camera settings can influence the width magnification trend for the corresponding stereoscopic images. This example uses the following camera settings:

- Camera sensor width = **Wc** = 24.0 mm (Super 35 size sensor)
- Camera lens focal length = **f** = 35.0 mm
- Convergence distance = **C** = 2094 mm

These images are viewed on a 65 in. diagonal 3DTV (**Ws** = 1436 mm) at a viewing distance **V** = 2094 mm by an adult human viewer with interocular eye separation **e** = 65 mm. Three stereo camera setups are used for this example. Setup A uses interaxial **t** = 65 mm with **h** = 0.543 mm = 2.26%, which is equal to the threshold value for a 65 in. 3DTV shown **Table 1**. Setup B uses interaxial **t** = 100 mm with **h** = 0.835 mm = 3.48%, which is greater than the threshold value for a 65 in. 3DTV. Setup C uses interaxial **t** = 32.5 mm with **h** = 0.272 mm = 1.13%, which is less than the threshold value for a 65 in. 3DTV. All three setups have been created so that they have the same convergence distance: **C** = (**tf**)/(2**h**) = 2094 mm.

Figure 9 is a plot of the width magnification factor calculated at different object distances **Zo** from the camera versus the image distance **Zi** where those object distances **Zo** will appear when viewed on the 65 in. 3DTV at viewing distance **V** = 2094 mm. The image distance **Zi** is calculated according to the following formula[3]:

$$Zi = (V*e*Zo)/(M*f*t - Zo*(2*M*h - e) \qquad (2)$$

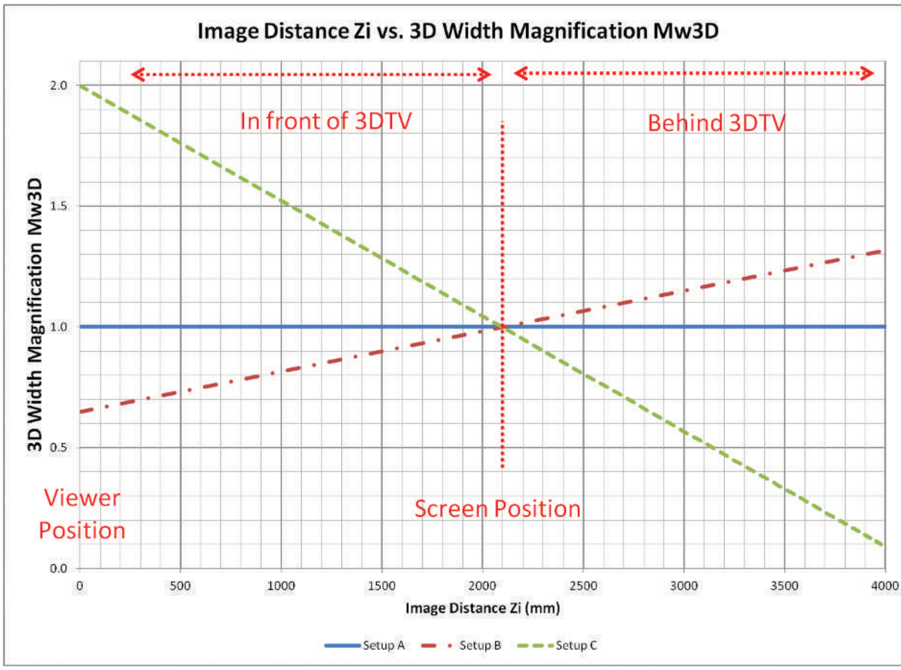

Figure 9. 3D width magnification vs. image distance.

If **Zi** = **V** (viewing distance) = 2094 mm, the image appears at the depth of the screen. If **Zi** is less than **V**, then the image appears to be in front of the 3D screen. Finally, if **Zi** is greater than **V**, the image appears to be behind the 3D screen.

Figure 9 shows the relative width magnification trend represented by the slope of the $\mathbf{M_{W3D}}$ versus **Zi** line for the example configurations, where the slope is increasing for Setup B, decreasing for Setup C and constant for Setup A. This means that objects appear to get larger as they move away from the camera and viewer for Setup B, objects appear to get smaller as they move away from the camera and viewer for Setup C, and objects appear to stay the same size as they move away from the camera and viewer for Setup A.

Suppose an example scene was photographed with the three example camera settings and that this example scene consisted of three soccer balls floating in the air above a grassy field; the soccer ball on the left side of the frame is 1400 mm from the camera, the soccer ball in the center of the frame is 2094 mm from the camera, and the soccer ball on the right side of the frame is 2800 mm from the camera. If the three images corresponding to the photographs from camera settings A, B, and C are viewed on a 65 in. 3DTV from a viewing distance of 2094 mm, then the soccer balls in each image will have different apparent perceptual sizes even though they have the same physical size on set in front of the camera, as shown in **Table 2**.

In this example scene, there are three objects in front of the camera at different distances from the camera, corresponding to object distance **Zo** equal to 1400, 2094, and 2800 mm, respectively. The objects are standard size-5 soccer balls with a diameter (object width **Wo**) of 220 mm. The image distance (**Zi**) and width magnification ($\mathbf{M_{W3D}}$) are computed for each object distance **Zo** for each corresponding camera setup using the equations for **Zi** and $\mathbf{M_{W3D}}$ described previously. The image width **Wi** is calculated by multiplying the object width **Wo** by the width magnification $\mathbf{M_{W3D}}$.

As shown in the three columns on the right side of **Table 2**, the width magnification is equal to 0.85 for the left soccer ball in Camera Setup B and is equal to 0.86 for the right soccer ball for Camera Setup C. This means that the viewer will perceive that the images of those two soccer balls are smaller than the regular size-5 soccer ball that was photographed on the set. The size of these smaller soccer balls is similar to a child's size-3 soccer ball, which is approximately 85% of a size-5 soccer ball. The width magnification is equal to 1.22

			Camera Setup			Camera Setup			Camera Setup		
			A	B	C	A	B	C	A	B	C
	Object Distance	Object Width	Image Distance			Image Width			Width Magnification		
Object	*Zo* (mm)	*Wo* (mm)	*Zi* (mm)			*Wi* (mm)			M_{W3D}		
Left soccer ball	1400	220	1400	1188	1678	220	187	264	1.00	**0.85**	1.20
Center soccer ball	2094	220	2094	2094	2094	220	220	220	1.00	1.00	1.00
Right soccer ball	2800	220	2800	3421	2396	220	269	188	1.00	1.22	**0.86**

Table 2. Viewer's perception of example stereoscopic images.

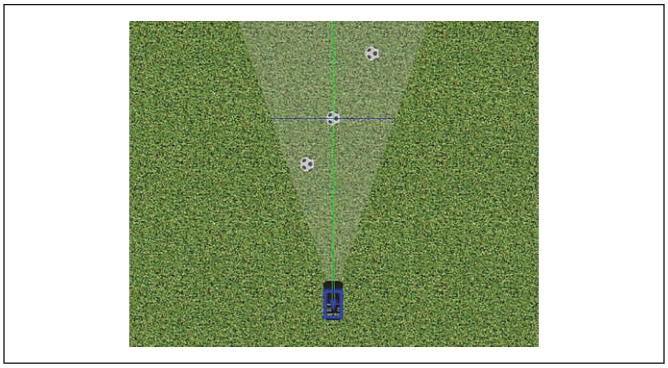

Figure 10. Bird's eye view of example scene with 3 soccer balls.

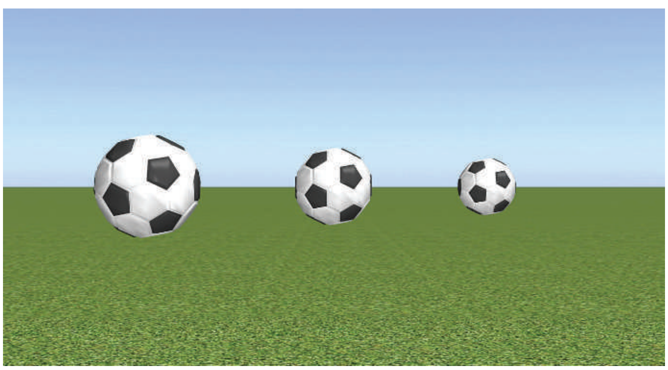

Figure 11. 2D image of example scene with 3 soccer balls.

for the right ball in Setup B and equal to 1.20 for the left ball in Setup C; therefore, these balls will appear to be approximately 120% of a size-5 soccer ball and thus appear larger than a normal soccer ball.

DEMONSTRATION AT SMPTE 2013 FALL CONFERENCE

During the presentation of this paper at the Society of Motion Picture and Television Engineers 2013 Annual Technical Conference and Exhibition, a 3D digital cinema package was shown that allowed the audience members to compare the perceptual size of soccer ball images shown on the large 18 ft 8 in. wide screen in the auditorium to different sized physical balls (yoga exercise balls with diameters of 750, 650, and 550 mm were used in this particular demo) that were held next to the 3D images shown on the screen. Because the images were prepared for the big screen, the images of the size-5 soccer balls were larger than regular life-size size-5 soccer balls (with a diameter of 220 mm) that were photographed by the virtual cameras used to photograph the example scene using the 3D previsualization software application FrameForge Previz Studio 3, Stereo Edition. A bird's eye view of the example scene is shown in **Fig. 10**, and a 2D image of the scene as photographed by the virtual cameras is shown in **Fig. 11**.

After the paper was presented and the example images were shown in the conference auditorium on the large 18 ft 8 in. wide screen, a similar set of images was shown to the conference attendees on a 55 in. 3DTV that was set up in the salon area. Conference attendees were able to compare the perceptual size of 3D images shown on the screen to the physical size-3 and size-5 soccer balls held next to the 3D images on the 55 in. 3DTV. In casual conversation after and during both viewing demos, one of the authors confirmed that in both the cinema-sized and the 3DTV screen setups the actual viewer's perception of the size of the images of the soccer balls was correctly predicted by the values of image distance (**Zi**), image width (**Wi**), and width magnification ($\mathbf{M_{W3D}}$) that are described in this paper.

The previous section of this paper used **Fig. 9** and **Table 2** to describe the scene and camera setup and the perceptual analysis of a set of three images (corresponding to Setups A, B, and C) prepared for a 65 in. 3DTV. During the conference, slightly different scene setups were used with different camera settings to prepare images for the 18 ft 8 in. wide screen and 55 in. 3DTV used for the demonstrations so that the perceptual size of the images presented could be compared with the physical dimensions of the props used during the demos.

For the 18 ft 8 in. screen demo, the following parameters were used:

- Camera sensor width = **Wc** = 24.0 mm (Super 35 size sensor)
- Camera lens focal length = **f** = 35.0 mm
- Convergence distance = **C** = 2800 mm
- Distance from ball (left, center, and right) to camera = **Zo** = 2065, 2800, and 3830 mm
- Shift **h** per eye for Setups A, B, and C = 0.137 mm (0.57%), 0.233 mm (0.97%), and 0.068 mm (0.29%)
- Camera separation **t** for Setups A, B, and C = 22, 37, and 11 mm
- Image resolution **Xres** = 1998 x 1080 (flat 1.85:1)

For the 55 in. 3DTV demo, the following parameters were used:

- Camera sensor width = **Wc** = 24.0 mm (Super 35 size sensor)
- Camera lens focal length = **f** = 33.0 mm
- Convergence distance = **C** = 1658 mm
- Distance from ball (left, center, and right) to camera = **Zo** = 1239, 1658, and 2243 mm
- Shift **h** per eye for Setups A, B, and C = 0.657 mm (2.69%), 1.100 mm (4.58%), and 0.323 mm (1.35%)
- Camera separation **t** for Setups A, B, and C = 65, 110, and 32.5 mm
- Image resolution **Xres** = 1920 x 1080 (16:9)

ANAGLYPH IMAGES FOR SMPTE JOURNAL

To further illustrate the perceptual size effects described in this paper, additional 3D images were created specifically for the *SMPTE Journal's* 182mm full-page width image size and are presented in red/cyan anaglyph format; 3D images in other formats that may lead to a higher quality viewing experience are available on the author's website at www.miksmith.com/3D2015/. The following parameters were used to generate the anaglyph images shown in **Figs 12-17**:

Figure 12. 3D image from Setup A in red/cyan anaglyph format, with left/center/right dice having the same perceptual sizes (15 mm, 15 mm, 15 mm).

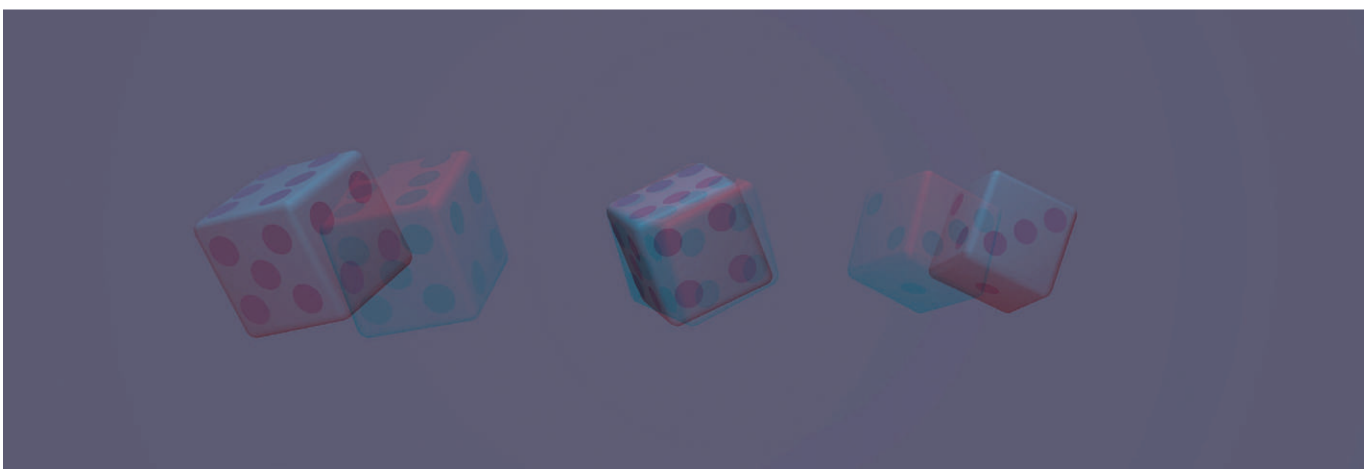

Figure 13. 3D image from Setup B in red/cyan anaglyph format, with left/center/right dice having the different perceptual sizes (14 mm, 15 mm, 16 mm).

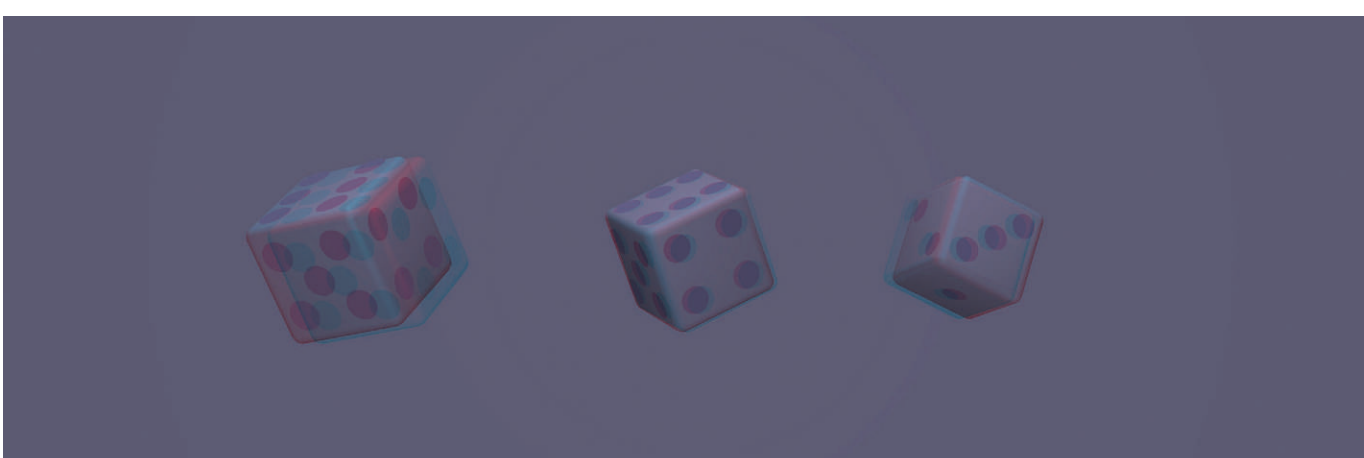

Figure 14. 3D image from Setup C in red/cyan anaglyph format, with left/center/right dice having the different perceptual sizes (17 mm, 15 mm, 14 mm).

- Camera sensor width = **Wc** = 24.0 mm (Super 35 size sensor)
- Camera lens focal length = **f** = 40.0 mm
- Convergence distance = **C** = 303 mm
- Distance from dice (left, center, and right) to camera = **Zo** = 260, 300, and 340 mm
- Shift **h** per eye for Setups A, B, and C = 4.28 mm (17.86%), 6.0 mm (25.0%), and 0.86 mm (3.57%)
- Camera separation **t** for Setups A, B, and C = 65, 91, and 13 mm

Figures 12, **13**, and **14** show the 3D image of the three dice photographed with Setup A, B and C, respectively. **Figures 15**, **16** and **17** show the 3D image of the left, center and right dice re-

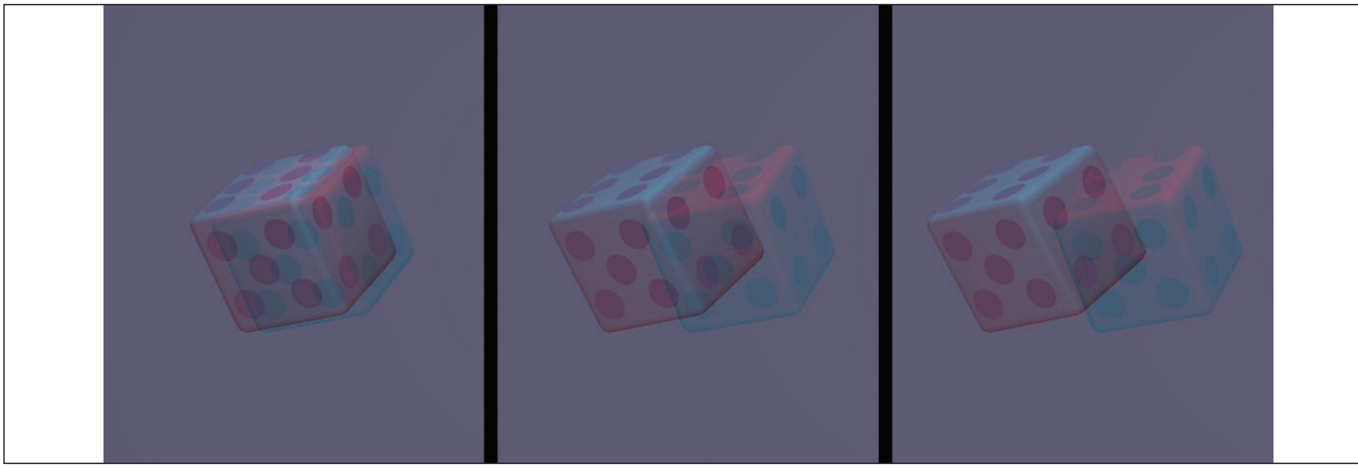

Figure 15. 3D image showing the left die from Setups C, A, and B, respectively in red/cyan anaglyph format having different perceptual sizes (17 mm, 15 mm, 14 mm).

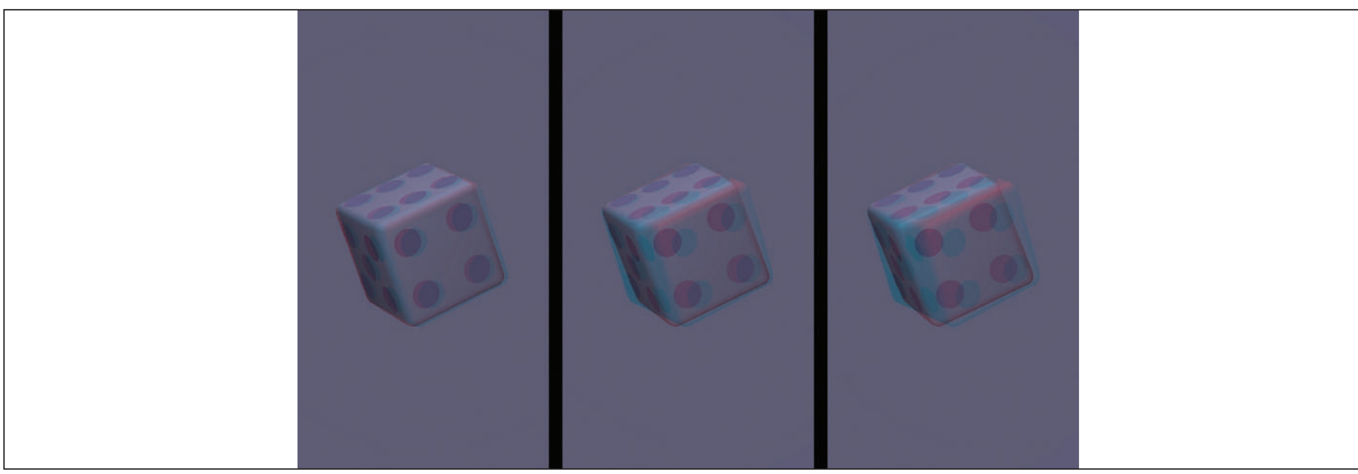

Figure 16. 3D image showing the center die from Setups C, A, and B, respectively in red/cyan anaglyph format having the same perceptual sizes (15 mm, 15 mm, 15 mm).

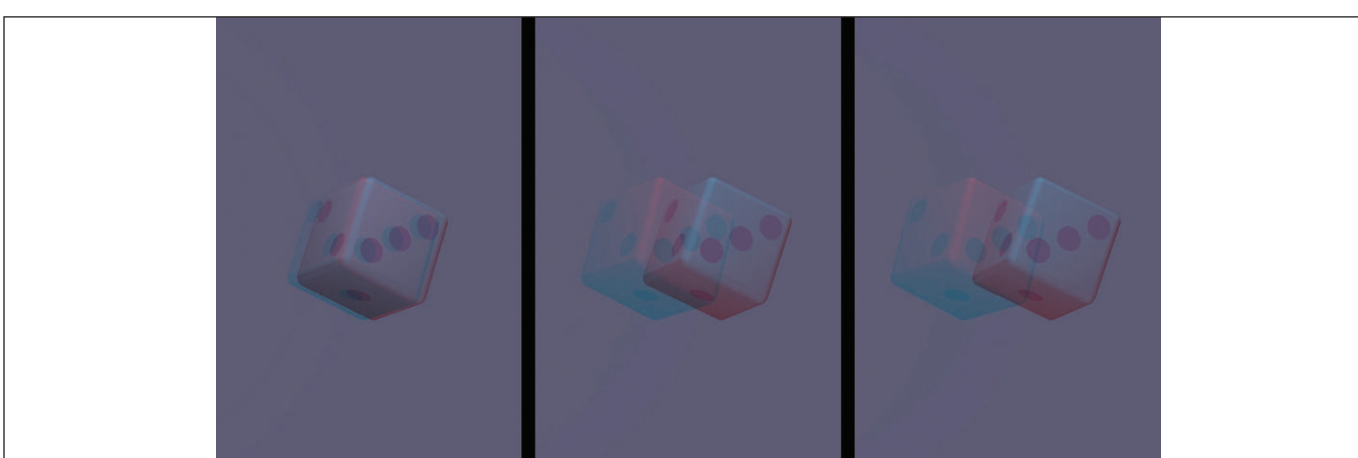

Figure 17. 3D image showing the right die from Setups C, A, and B, respectively in red/cyan anaglyph format having the different perceptual sizes (14 mm, 15 mm, 16 mm).

spectively from Setup C, A and B. The left dice shown in **Fig. 15** have respective 3D image widths **Wi** = (17 mm, 15 mm, 14 mm). The center dice shown in **Fig. 16** have respective 3D image widths **Wi** = (15 mm, 15 mm, 15 mm). The right dice shown in **Fig. 17** have respective 3D image widths **Wi** = (14 mm, 15 mm, 16 mm). The 2D image width of each dice in **Figs. 15**, **16**, and **17** is the same (17.5 mm, 15.2 mm, 13.4 mm, respectively) since each dice is the same distance (260 mm, 300 mm, 340 mm) from the camera respectively.

MISUNDERSTANDING REGARDING MINIATURIZATION

A widespread misunderstanding in the industry is that miniaturization only happens when the interaxial camera separation **t** is larger than the human eye separation (interocular) **e** = 65 mm and that gigantism only happens when the interaxial is less than the human eye separation. For example, in Kroon,[5] the following definitions are provided for *hyperstereo* and *hypostereo* with accompanying incomplete summaries of the effect of apparent image size:

hyperstereo—using an interaxial distance that is larger than the interocular distance of the nominal viewer when recording a stereogram. This enhances stereo depth while reducing apparent image scale, causing objects to appear as if they are unusually small.

hypostereo—using an interaxial distance that is smaller than the interocular distance of the nominal viewer when recording a stereogram. This increases apparent image scale, causing objects to appear as if they are unusually large (p. 88).[5]

The 65 in. 3DTV example with Setups B and C described in this paper provide an example how these widely used industry definitions are not entirely true. Camera Setup B, using a larger-than-interocular camera interaxial **t** = 100 mm, causes the right soccer ball to appear to be 122% of the size of the soccer ball on set (contrary to the typical industry misunderstanding described earlier in the hyperstereo definition). Setup C, using a smaller-than-interocular camera interaxial **t** = 32.5 mm, causes the right soccer ball to appear to be 86% the size of the soccer ball on set (contrary to the typical industry misunderstanding described in the hypostereo definition).

CONCLUSION

While stereoscopic production has mostly focused on depth and volume,[1,4] we believe additional focus on the width magnification factor during the production process is straightforward and could lead to better control of the audiences' perception of the size of objects. This paper illustrates the use of width magnification as a tool to predict both the absolute and the relative size of objects viewed in stereoscopic 3D.

We expect that the absolute value of the width magnification affects the visual impact of the stereoscopic imagery, because small or tiny objects do not have the same visual impact and seriousness as normal-sized or larger-than-life objects. We expect that the relative value of the width magnification in different parts of the image affects scenes in which multiple objects of the same size are shown in the same image, such as 2-shot scenes, crowd scenes, and images with architectural elements.

Another way to consider the effects of screen size on the width magnification of objects is to view the content on different screen sizes during dailies review and other viewing opportunities that occur during the production process. We expect that if more attention is given to width magnification during production, post-production, distribution, and display, it will lead to more consistency between a viewer's expected size of objects based on the story and a viewer's actual perception of the size of those objects. We expect that controlling miniaturization and size perception will improve the impact of stereoscopic 3D storytelling and make the viewing experience more controlled when viewing on different screen sizes.

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REFERENCES

1. Bruce Block and Philip McNally, *3D Storytelling: How Stereoscopic 3D Works and How To Use It*, Focal Press: Burlington, MA, 2013.
2. Raymond Spottiswoode, N. L. Spottiswoode, and Charles Smith, "Basic Principles of the Three-Dimensional Film," *J. SMPTE*, 59: 249–286, Oct. 1952.
3. Michael D. Smith and Bradley T. Collar, "Perception of Size and Shape in Stereoscopic 3D Imagery," in *Proc. 23rd SPIE Conference on Stereoscopic Displays and Applications*, South San Francisco, CA, pp. 828810I–828810I31, Jan 2012.
4. Bernard Mendiburu, *3D Movie Making: Stereoscopic Digital Cinema from Script to Screen*, Focal Press: Oxford, United Kingdom, 2009.
5. Richard W. Kroon, *Technicolor's Guide to 3D for Film, TV, and Everything In-Between*. Technicolor: Hollywood, CA, 2011.

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