Comparison of 3-D Display Formats for CAD Applications

by

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ABSTRACT

Two experiments were performed to rank different types of display formats common to CAD applications in terms of geometric information conveyed and perceived realism of objects. Display types tested were: wireframe, wireframe with hidden lines removed (HLR), shaded solid, orthogonal multi-view, stereoscopic wireframe, stereoscopic HLR, and stereoscopic shaded solid. The results of the geometric information experiment indicated that the orthogonal multi-view display was judged inferior to both the non-stereo and stereo pictorial displays and that the stereo displays were judged superior to the non-stereo displays in providing geometric information to the subject. Individual preferences among subjects, however, varied widely. The results of the realism experiment indicated that the flat shaded stereo, HLR stereo, and the flat shaded display types were judged to be equivalent and most realistic. The wireframe stereo, HLR, and wireframe displays were judged to be equivalent and less realistic. The orthogonal views display was judged to be the least realistic.

1. INTRODUCTION

Since the introduction of shutter systems based on liquid crystal (LC) modulators several commercial systems for time-multiplexed stereoscopic display of images have become available. There have been, however, very few controlled studies indicating their effectiveness for display of data as compared to identical 2-D perspective displays or of user acceptance of CRT-based stereoscopic displays. There have been even fewer studies that supported their use for specific visual tasks.[1] This lack of documented, non-anecdotal evidence is due partially to the newness of the technology, but is compounded by the lack of understanding of basic image generation and presentation factors that are unique to a time-multiplexed stereoscopic display environment.

The research that does exist indicates that time-multiplexed stereoscopic displays provide better user performance at many 3-D visual tasks than perspective 2-D displays. Recent studies have compared user performance with 2-D perspective display versus time-multiplexed stereoscopic display for both accuracy and reaction times. Stereoscopic displays have been judged superior for visual search and interactive cursor positioning tasks[2, 3], for spatial judgement tasks[4, 5, 6], and for communication of design information.[7] User acceptance of stereoscopic display systems, however, depends not only on task performance improvement but also on the users' subjective perceptions of image quality and information content. A recent study[8] indicates that, in 3-D task environments, worker acceptance of display formats is higher for stereoscopic displays than for 2-D perspective displays. Problems with flicker, ghosting, or excessive parallax in stereoscopic displays, however, can have an adverse affect on worker acceptance. For instance, in experiments on depth discrimination performance, it was shown that ghosting in an image strongly affected subjective ratings of display image quality, even though its effects on discrimination performance were minimal.[9] Our research addresses subjects' preference for different modes of display in engineering design visualization. Various modeling and display techniques were tested, including: wireframe, wireframe with hidden lines removed, shaded solid, orthogonal views, stereoscopic wireframe, stereoscopic wireframe with hidden lines removed, and stereoscopic shaded solid.

2. METHOD

2.1 Subjects

Twenty students of Introductory Engineering Design and Graphic Communication at the Georgia Institute of Technology in Atlanta served as subjects in this study. The subjects were 18 to 24 years of age, and consisted of four

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females and sixteen males. The subjects were given class credit for participation in this investigation. All subjects reported normal or corrected-to-normal vision and reported some previous computer experience.

2.2 Apparatus and stimuli

For our experiments, all stereoscopic images were presented in a time-multiplexed manner at 60 Hz., on a Silicon Graphics 4D/120 GTX superworkstation equipped with a Tektronix liquid crystal modulator (LCM). In a time-multiplexed scheme, left and right-eye perspectives of an object are alternated on the screen while the LCM encodes each perspective with either left or right-handed circular polarization. The subjects wore circularly polarized glasses that allowed only the correct image to reach each eye.

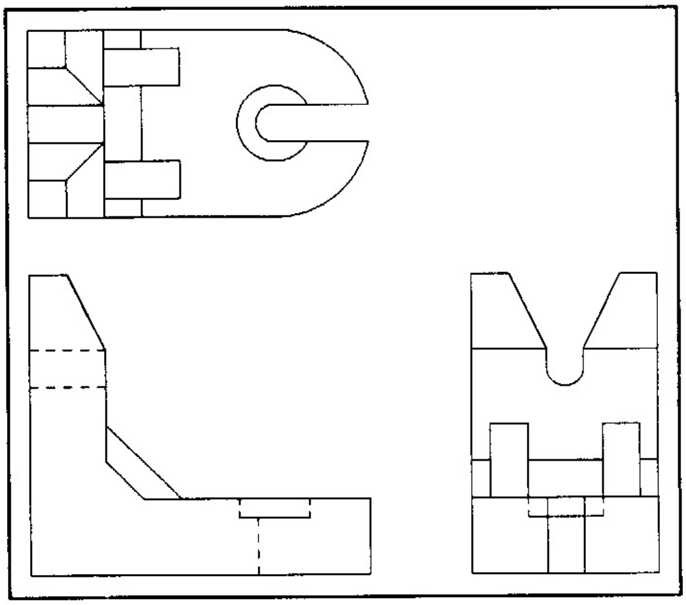

Figure 1. The third-angle projection orthogonal view display.

The display types presented to the subjects were wireframe, hidden line removed (HLR) solid, flat-shaded solid, third-angle projection orthogonal views, stereoscopic wireframe, stereoscopic HLR solid, and stereoscopic flat-shaded solid. The images comprising these displays were rendered by CADKEY SOLIDS on a Silicon Graphics Personal IRIS Workstation from a model developed using CADKEY on a 386-based personal computer. All stereoscopic images were generated using on-axis projection techniques.[10] Maximum horizontal disparity was less than 1.6 degrees for all parts of the model, and all images were rendered in shades of red to minimize ghosting. The images were transferred to the Silicon Graphics 4D/120 GTX as raster files. The orthogonal views, wireframe, and hidden line removed images used in this study are shown in figures 1, 2, and 3. The model was not varied across subjects or experiments. To achieve the stereo display of these images, the left-eye and right-eye perspective images were alternated on the screen as previously described. To achieve the non-stereo images, the right-eye image was presented to both the left and right eyes. The stereoscopic modulator was active throughout the experiment for both stereo and non-stereo displays.

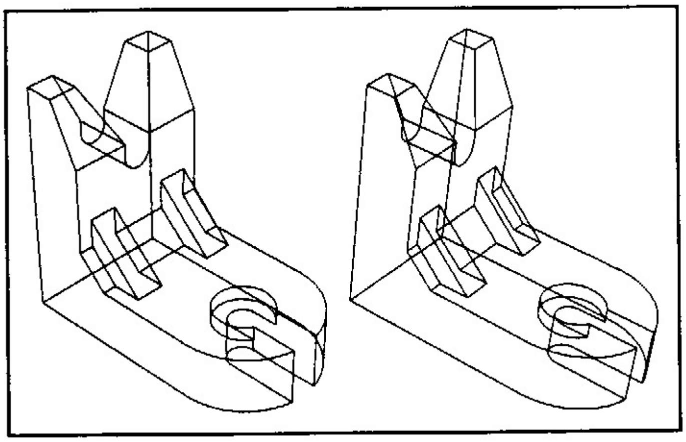

Figure 2. The wireframe display. The left and right eye views are reversed in this figure.

The software written to present the displays to the subject also facilitated recording the actions of the subject and all relevant time data.

2.3 Procedure

In these experiments, a within-subjects experimental design was used to rank the display formats by an interactive paired comparison. In the first experiment, a group of ten subjects was presented the pairs of display types on the computer monitor in random order and asked to select which of the two display types was more helpful in understanding the geometry of the object. In the second experiment, a group of ten subjects was asked to select which of the two display types was more realistic. The two paired displays were presented sequentially, and the subjects were permitted to switch between the two displays as desired. The computer screen was blanked during the time the image was being written to the display buffer so as to present only complete images to the subject. The subjects judged all possible pairs.

For each pair, the time each display was visible, the number of times the subject switched between the paired displays, and the subject's choice of display was recorded by the computer. Following the experiments, the subjects were given a questionnaire to obtain data on the subjects' age, sex, history of color blindness, vision, computer experience, and handedness. The subjects were also asked if any problems were encountered during the experiment, such as visual fatigue viewing the stereographic displays.

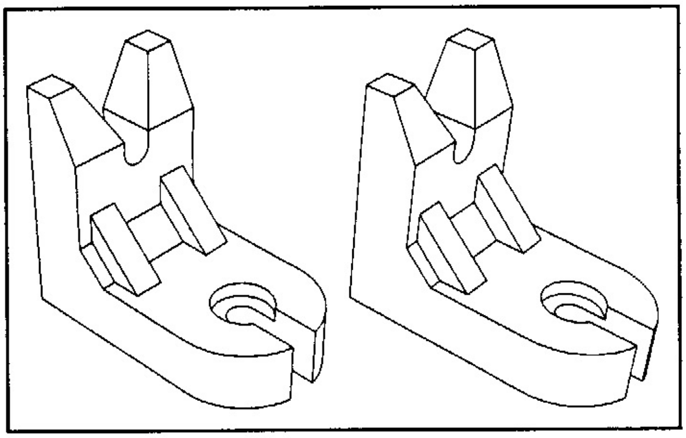

Figure 3. The hidden line removed display.

3. RESULTS

The data on the subject's display preference were converted to percentile ranks. The percentile rank of a display's score is defined as the percentage of the displays with scores at or below that display's score value. For instance, in the first experiment, the score assigned to each display type is the number of displays in the experiment that were judged by the subject to be inferior in helping the subject understand the geometry of the object. The highest possible score of a set of seven displays is 6, when all other displays are judged to be inferior; and the lowest possible score is 0, when no other display was judged to be inferior. The percentile rank of a score of 6 is 100, as 100% of the displays' scores are at or below the score of the display in question. The total time each display type was available to each subject also was calculated.

Table I. Percentile ranks and presentation time means and standard deviations by display type for the geometric information content judgement.

	Percentile Rank		**Presentation Time *(seconds)***	
Display Type	*Mean*	*Std Dev*	*Mean*	*Std Dev*
Orthogonal Views	15	25	47	16
Wireframe	50	31	66	25
HLR	32	12	51	9
Flat Shaded	47	28	60	10
Wireframe Stereo	72	28	83	25
HLR Stereo	65	22	78	19
Flat Shaded Stereo	70	30	76	17

The results of the geometric information judgement are summarized in table I. The orthogonal views display was often judged to be most inferior by the subject (percentile of 15), the non-stereo pictorial displays were judged to be superior (percentiles of 32 to 50) to the orthogonal views, and the stereo pictorial displays were often judged to be most superior (percentiles of 65 to 72) in helping the subject understand the geometry of the object. As shown by table I, presentation time for each display type followed the trend observed in the percentile ranking data: the orthogonal views and HLR non-stereo displays were viewed for a mean time of 47 seconds and 51 seconds, respectively; the flat shaded and wireframe non-stereo displays for 60 and 66 seconds, respectively; and the flat shaded, HLR, and wireframe stereo displays for 76, 78, and 83 seconds, respectively. Of particular note, however, are the individual differences between subjects in their judgement of displays.

Individual differences between subjects are highlighted by figure 4. The center mark on each bar represents the mean percentile rank for that display type from table I. The width of the bar represents one standard deviation on each side of the mean percentile. Therefore, 68% of the subjects' responses falls within each bar. For instance, although the orthogonal views display was generally ranked lowest among all displays, this figure illustrates that some subjects judged the orthogonal views display to be superior to other displays. The stereo pictorial displays are shown to be equivalent, the non-stereo pictorial displays to be equivalent and to show some ranking similarity to their stereo counterparts, and the orthogonal views display shows some ranking similarity to the non-stereo pictorial displays, although ranked lowest, particularly to the HLR non-stereo display.

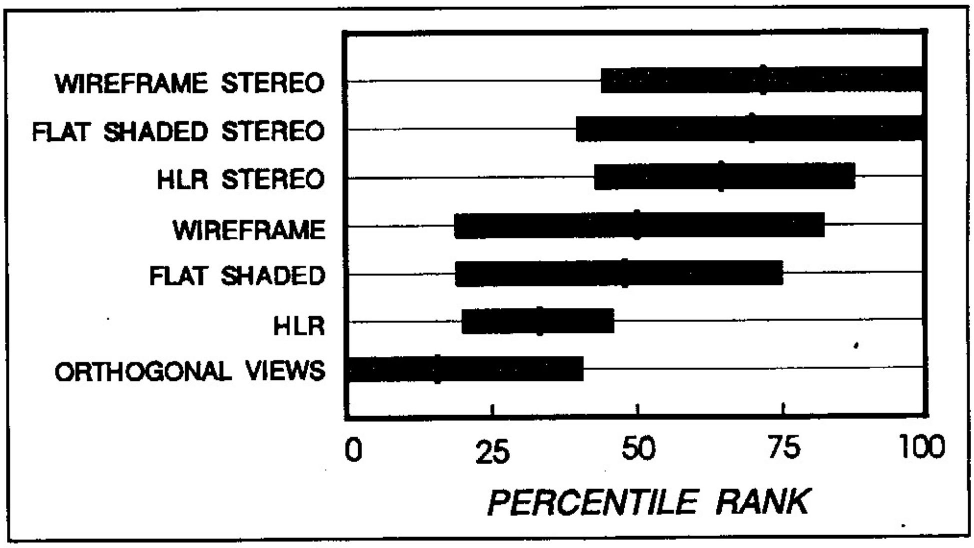

Figure 4. The geometric information judgement: Comparison of percentile ranks. The center mark on each bar represents the percentile rank for that display from table I. The bar extends one standard deviation on each side.

The results of the realism judgement are summarized in figure 5. The flat shaded stereo, HLR stereo, and the non-stereo flat shaded display types were judged to be equivalent and judged to be most realistic (percentiles of 62 to 78). The wireframe stereo, HLR, and wireframe displays were judged to be equivalent and less realistic (percentiles of 42 to 45) than the above mentioned displays. The orthogonal views display was judged overwhelmingly to be the least realistic (percentile of 10) display type.

4. DISCUSSION

The results of the geometric information judgement follow analysis of available depth and shape information in each display. The hidden line removed display is ambiguous due to several possible interpretations of geometric orientation from a line drawing (Necker illusion). The wireframe display provides a more detailed shape description by including geometry occluded in the HLR display, although the ambiguity associated with the Necker illusion also applies to wireframe displays. The flat-shaded display provides additional cues to surface orientation. The addition of stereopsis to these three displays adds an additional depth cue useful in eliminating geometric ambiguities. The judgements of the subjects as to which display helps them better understand the geometry of the object follows this analysis, with the exception of the third-angle projection orthogonal view display.

The display of orthogonal views was the only non-pictorial display type presented. The subjects, although students of Engineering Design and Graphic Communication, were not exposed to orthographic multiview techniques at the time of the experiment. This would explain the subjects judgement of the orthogonal view display as inferior; a novice finds difficulty in interpreting an orthographic multiview projection, and does not benefit from it's geometric description. A pictorial, and particularly a stereo pictorial, however, more closely resembles the subject's every-day experience with objects.

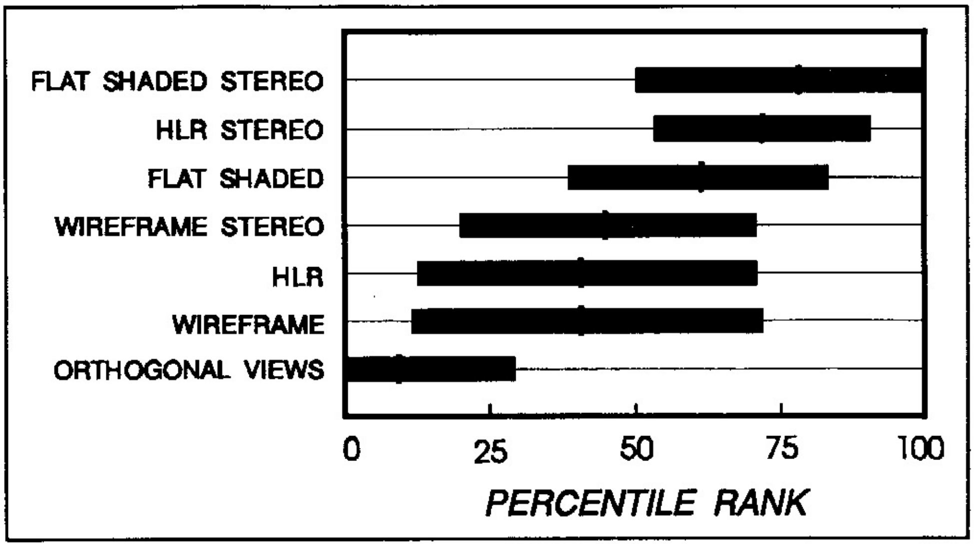

Figure 5. The realism judgement: Comparison of percentile ranks. Each bar extends one standard deviation from the mean, representing 68% of the subjects' responses.

The results of the realism judgement are of particular interest. The ranking of the flat shaded displays over the HLR displays was expected and is consistent with previous studies.[11, 12] HLR displays are useful, however, due to the speed at which they can be rendered compared to a shaded model. The data shows, however, that a stereo HLR display was judged to be as realistic as a non-stereo flat shaded display. The addition of stereo cues to an image is computationally cheaper than rendering a shaded image, so the data suggests flat shading cues could be supplanted by stereo cues without loss of perceived realism in the image. The savings in rendering time per image is significant. A stereo HLR image can be rendered in real time on many machines that are not capable of real time rendering of shaded displays. This realism effect does not carry over to wireframe images with hidden lines shown. The data shows that the addition of stereo to a wireframe display does not add to its perceived realism.

The individual differences reflected in the standard deviations of the percentile ranks are at least partly a result of individual inconsistencies in the subject's judgements. In some instances, a subject would judge display A to be superior to B, B superior to C, and C superior to A. This clearly cannot be so, and affects the data accordingly. This type of response, however, does imply a within-subject variance in addition to the between-subjects variance of individual differences. A few subjects reported negligible eyestrain while viewing the stereo displays, possibly due to disparate vergence and accommodation cues.

Further research is warranted. An investigation of a subject's subjective rating of these display types would further elucidate the mechanisms that help a novice understand the geometry of an object. Varying the object complexity would also reveal the effect of confusion and misinterpretation of wireframe displays, with possible clarification by the addition of stereopsis. The effect of these display types on a measure of performance would also reveal the relationship between the subject's reported perception, and the subject's use of the available geometric information.

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