

Task Validation of Display Temporal-Resolution Measurements

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ABSTRACT

We have recently described a perceptual technique for assessing the temporal resolution of display systems used in Air Force flight-simulators. That technique was based on the assessment of the perceived blur of a simple stimulus consisting of a pair of moving vertical lines. In the present study, we have attempted to validate our previous technique by correlating it directly with performance on simplified tasks that may be performed during training in a high-fidelity Air Force flight simulator. Data were obtained by asking observers to; 1) detect whether or not a moving F-16 target-aircraft banked as it moved laterally across the observers' field-of-view, and 2) judge whether changes in aircraft pitch resulted in blurring of the associated moving terrain. The level of moving-image blur was determined by the length of time that the image was presented during each video frame (i.e., the projector hold-time) on a digital (DLP) projector. The results were compared to those obtained using a standard CRT projector, whose effective hold-time was about one-quarter of that of the lowest DLP hold-time tested. For both the roll detection task and the aircraft pitch task, results with the DLP projector did not differ significantly from that obtained with the CRT when the DLP hold-time was reduced to 5.8 msec. These results are in qualitative agreement with those obtained using the simpler moving-line test, and suggest that the latter is a valid measure of display temporal resolution in the context of flight-simulator applications.

ABOUT THE AUTHORS

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INTRODUCTION

Digital devices, such as liquid crystal displays (e.g., LCD, LCoS, and FLCoS), and digital light projectors (DLPs), have relatively high spatial resolution, but their temporal resolution is limited compared to CRTs. This limited temporal resolution often results in the blurring of moving images (Klompener & Velthoven, 2004; Kurita, 2001; Nakamura & Sekiya, 2001). DLP and FLCoS displays have very fast response times (in terms of onset and offset), but still exhibit significant moving-image blur. This indicates that the primary determinant of blur is the time that the image is presented during each frame, referred to here as the display hold-time. The blur produced by long hold-time devices is sufficiently severe to render them unsuitable for many flight-simulation and training applications.

The practical importance of measuring temporal resolution in applied settings such as flight simulation dictates the development and use of relatively simple techniques whose results are easily interpreted. We have previously described such a technique, which is based on assessing the perceived blur of a simple stimulus consisting of two vertical moving lines (Winterbottom, *et al.*, 2004). Related procedures, such as the Motion Picture Response Time (MPRT), have been proposed (see e.g. Igarashi, *et al.*, 2003; Oka, & Enami, 2004; Igarashi, *et al.*, 2004), but they are generally more complex, require more expensive equipment, and do not directly assess perceived blur.

We have previously reported that perceived blur was significantly reduced for LCD and LCoS projectors when their hold-time was reduced using mechanical shutters (Winterbottom *et al.*, 2006; 2007). Further, Winterbottom, *et al.* (2006) reported that experienced pilots rated moving image quality as significantly higher when imagery was displayed using a shorter hold-time. Winterbottom, *et al.* (2007) extended those results by assessing perceived blur using either moving aircraft targets or a moving horizon. They found that both pilots and non-pilots perceived less blur as display hold-time was decreased.

Additionally, they reported that a reduction in hold-time to about 4 msec resulted in perceived blur that was not significantly different from that associated with a CRT display.

In the present study, we have attempted to extend the results of Winterbottom, *et al.* (2006, 2007) by assessing the effects of display hold-time on the performance of two tasks using imagery similar to that encountered in Air Force flight simulation and training. It was expected that these results would correlate with previous data, and that they could be used to further validate the moving-line technique, which has been used to assess the temporal resolution of Air Force flight-simulator displays.

DISPLAY CHARACTERIZATION

A Christie Matrix S+2K DLP projector and Barco 909 CRT projector were used for testing and experimentation. The pixel count was 1400×1050 and 1280×1024 for the DLP and CRT, respectively. The Christie DLP projector was equipped with a function called Accuframe, which allowed hold-time to be varied. The three DLP hold-times tested here were 5.8, 7.4, and 16.6 msec, which corresponded to Accuframe levels of 0, 128, and 254, respectively.

Methods

Maximum Luminance and Contrast

Maximum luminance was measured by averaging the luminances of the two center white squares of a 4×4 black and white checkerboard pattern that covered the entire display area (VESA, 2001). Maximum contrast was measured by calculating the Michelson contrast of the mean of the two center white squares and the two center black squares of the checkerboard.

Spatial Resolution

Display spatial resolution was assessed using techniques adapted from accepted measurement standards (Geri, Winterbottom & Pierce, 2004; VESA, 2001). This involved measuring the Michelson contrast of grille lines that were 3, 2, and 1 pixels wide. Resolution was determined by dividing the number of addressed lines by the grille line width

required to reach 25% contrast. Luminance measurements were also obtained.

Temporal Resolution: Display Temporal Response

Temporal resolution was measured using a photodiode and Fluke Scopemeter. Each display's response to a 30 Hz test pattern was recorded.

Temporal Resolution: Perceived Blur

Observers were instructed to track a test pattern consisting of two white vertical lines (DAC = 255) moving at speeds ranging from 4 to 45 deg/sec (100 to 1200 pixels/sec). The background was black (DAC = 0), and the lines were 100 pixels in length, and 1 pixel wide. Observers adjusted the separation of the lines such that the gap between them was just visible, and such that the lines were equal in width. If the lines appeared blurred (i.e. appeared to be wider than 1 pixel), the observers had to increase the gap width in order to see the lines as separate, thus the adjusted gap width was taken as a measure of perceived blur.

Results

Maximum Luminance and Contrast

Maximum luminance for the DLP with hold-times of 16.6 msec and 5.8 msec was approximately 100 fL and 34 fL, respectively. Thus, the reduction in hold-time is associated with a concomitant loss in luminance. The maximum luminance of the CRT was approximately 15 fL.

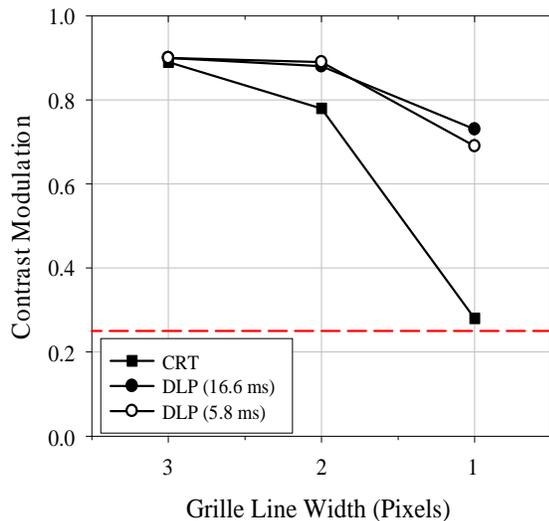


Figure 1. Michelson contrast as a function of grille-line width for the two hold-times of the DLP projector, and for the CRT display. The dashed line indicates the 25% criterion level.

Spatial Resolution

Michelson contrast as a function of grille line width for the DLP and CRT projectors is shown in Figure 1. Contrast for both displays was over 25% for all grille-line widths, indicating that measured resolution was higher than the pixel count for both projectors. The measured horizontal spatial resolution, calculated by extrapolating the grille line width necessary to reduce contrast to 25%, was 3864 lines for the DLP and 1434 lines for the CRT. As shown, varying the hold-time of the DLP had no significant effect on contrast (and hence spatial resolution).

Temporal Resolution: Display Temporal Response

Shown in Figure 2 is the light output of the DLP display to a half-cycle of the 30-Hz test pattern for the shortest hold-time tested. For the DLP projector, measured hold-times were 16.6, 7.4, and 5.8 msec. The hold-time of the CRT was about 1.4 msec (at 50% amplitude).

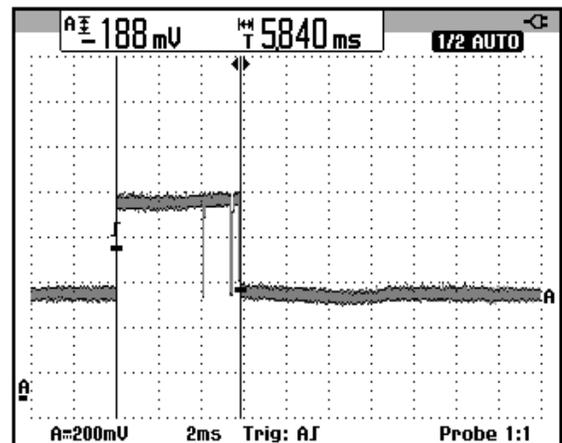


Figure 2. Light output of the DLP for the shortest hold-time (5.8 msec, Accuframe = 254) in response to a 30 Hz test pattern.

Temporal Resolution: Perceived Blur

Shown in Figure 3 is the adjusted gap-width (i.e. perceived blur) of the moving-line stimulus as a function of line speed for the three DLP hold-times, and for the CRT. Reducing hold-time significantly reduced perceived blur. The results of an Analysis of Variance indicated that the main effects of Speed [F(4, 40) = 451, p < 0.001], and Hold-time [F(3, 40) = 395, p < 0.001], and the Speed x Hold-time interaction [F(12, 40) = 73, p < 0.001] were significant. Post-hoc tests indicated that the 16.6 and 7.4 msec hold-times resulted in perceived blur that was significantly greater than for the CRT. However, perceived blur for the 5.8 msec hold-time was not

statistically different (averaged across speed) from that of the CRT.

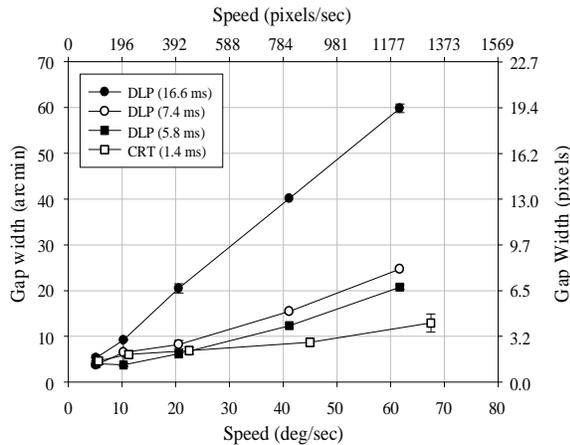


Figure 3. Moving-line gap width (perceived blur) as a function of line speed and display hold-time.

AIRCRAFT ROLL DETECTION

Methods

Observers

Four observers with normal or corrected to normal vision participated.

Apparatus and stimuli

The Barco CRT projector and Christie DLP were used to project images that subtended 52" × 43" (72° × 62°) and 52" × 29" (72° × 44°), respectively. The luminance was adjusted to about 13 fL at the center of each image. The stimulus was an F-16 model which moved from left to right across the screen at speeds of 8.0, 17.5 or 35.0 deg/sec (435, 957, or 1961 knots).

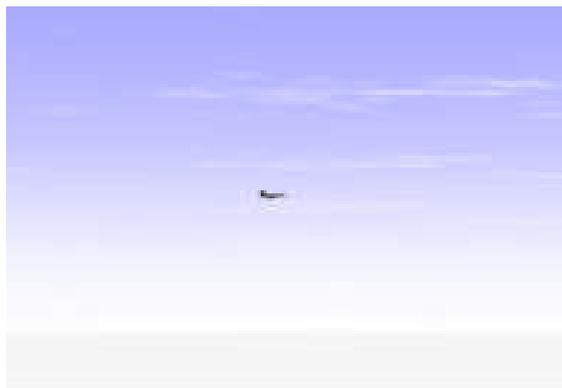


Figure 4. Screen capture of F-16 target aircraft with 19 deg roll angle at the 1600 m simulated distance used in Aircraft Roll Detection experiment.

The moving F-16 model (shown in Figure 4) was displayed for approximately 2 sec during each trial. Half way through the trial, the F-16 rolled 4, 7, 10, 13, 16, or 19 deg. The observers' task was to track the aircraft and indicate, using a 2-button response box, whether or not it rolled. The minimum roll-angle that could be detected was estimated for the three speeds at each of the four hold-times.

Observers viewed the display from a distance of 36". The simulated distance of the F-16 was 1600 m, which corresponded to a target size of approximately 34 arcmin, (horizontal). Image size and viewing distance were selected to match as closely as possible the conditions in the Mobile Modular Display for Advanced Research and Training (M2DART, see e.g. Wight, Best, and Pepler, 1998).

Results

Shown in Figure 5 is the proportion of correct detections of aircraft roll as a function of roll angle for the three target speeds tested at each of the four display hold-times. Roll-detection performance increased with roll angle, but the increase was generally slower for the higher target speeds. Figure 6 shows threshold roll angles obtained from the data of Figure 5 using a 75% response criterion (dashed line in Figure 5).

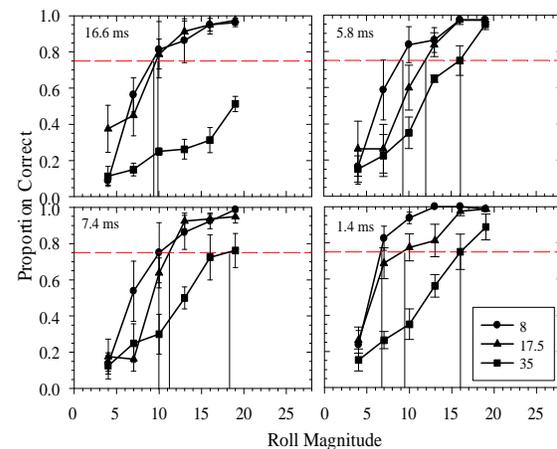


Figure 5. Proportion of correct roll detections for each display hold-time, and target speed tested. Vertical lines indicate threshold estimates for roll detection.

A repeated measures ANOVA (Huynh-Feldt corrected) indicated that the effects of Hold-Time [$F(3, 9) = 6.7, p < 0.05$], and Speed [$F(2, 6) = 47.4, p < 0.001$] were both significant. The Hold-Time × Speed interaction was not significant [$F(6, 18) = 2.4,$

$p = 0.13$]. Threshold generally increased with speed for all hold-times. A set of planned comparisons indicated that roll thresholds for the 16.6 msec hold-time were significantly different [$F(1, 3) = 70.1, p < 0.01$] than those for the CRT (1.4 msec Hold-time), Roll thresholds for the 7.4 msec hold-time were marginally different [$F(1, 3) = 9.4, p = 0.055$] from those obtained with the CRT, but thresholds for the 5.8 msec hold-time were not significantly different [$F(1, 3) = 2.0, p = 0.25$] from those of the CRT.

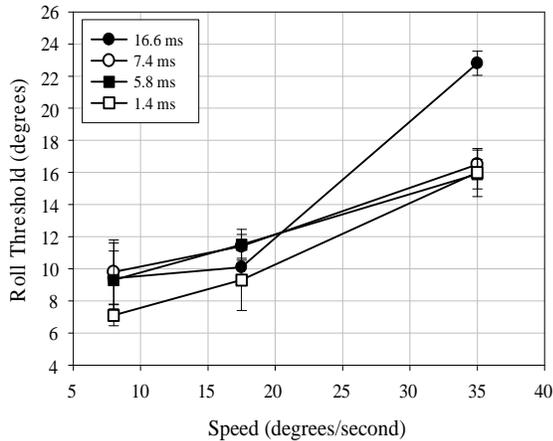


Figure 6. Roll detection thresholds for each target speed and display hold-time.

AIRCRAFT PITCH-RATE BLURRING

Methods

Observers

Three observers with normal or corrected to normal vision participated.

Apparatus and stimuli

The Barco CRT projector and Christie DLP were used to project images that subtended $52'' \times 43''$ ($72^\circ \times 62^\circ$) and $52'' \times 29''$ ($72^\circ \times 44^\circ$), respectively. The luminance was about 13 fL at the center of each image. The stimulus was a view of a flight database near Nellis AFB, NV at an altitude of 5,000 m (16,404 ft).

Procedure

An upward pitching motion was simulated with no forward motion. The observer saw the horizon move once from top to bottom. The magnitude of the movement was 45 deg centered on the center of the display. The pitch rate was varied from 6 deg/sec to 10 deg/sec. Pitch rate was constant throughout the full range of motion. The observers' task was to track the moving horizon and indicate, using a 2-button response box, whether or not the terrain appeared

blurred. Observers viewed the display from a distance of 36''. Image size and viewing distance were again selected to match as closely as possible the conditions in the M2DART.

Results

As shown in Figure 7, for all DLP hold-times, observers perceived more terrain blurring as pitch rate increased. Further, perceived blur decreased as hold-time decreased. For the CRT, however, observers did not perceive blur for any pitch rate tested. For a DLP hold-time of 5.8 msec, perceived blur was nearly equal to that of the CRT for pitch rates less than 9 deg/sec. A repeated measures ANOVA indicated that the main effects of hold-time [$F(3, 6) = 51.6, p < 0.001$] and pitch rate [$F(4, 8) = 48.3, p < 0.01$] were significant, as was the Hold-Time \times Pitch Rate interaction [$F(12, 24) = 27.5, p < 0.001$]. Additionally, planned comparisons indicated that a DLP hold-time of 16.6 msec resulted in significantly more blur than the 1.4 msec hold-time of the CRT [$F(1, 2) = 99.2, p = 0.01$], and a DLP hold-time of 7.4 msec resulted in marginally increased blur [$F(1, 2) = 11.6, p = 0.076$] relative to the 5.8 msec hold-time. Pitch blur with a DLP hold-time of 5.8 msec was not significantly different than that for the CRT [$F(1, 2) = 3.5, p = 0.202$].

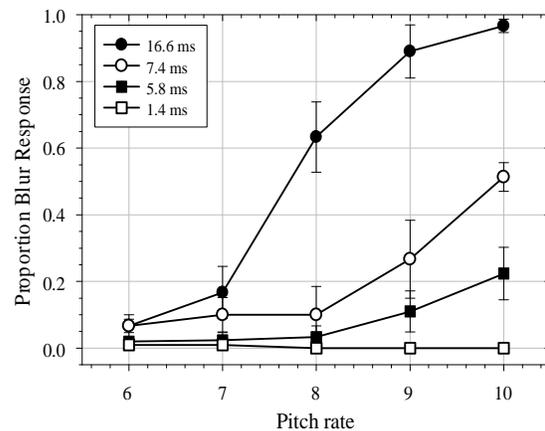


Figure 7. Proportion of the trials on which pitch-rate blur was perceived as a function of pitch rate for the DLP and CRT (hold-time=1.4) displays.

DISCUSSION

CRTs are generally considered the standard for temporal resolution, and it is the display technology currently used in most Air Force flight simulators. Sample and hold type displays, like the DLP tested here, have generally been unacceptable for flight simulation due to long hold-times and subsequent

moving image blur. However, the DLP projector evaluated here performed nearly as well as the CRT when DLP hold-time was reduced to about 5.8 msec. Display performance was assessed using air-to-air target speeds and aircraft pitch rates likely to be encountered in Air Force flight simulation, and so it appears that digital projectors that can provide hold times less than about 6 msec may be suitable in many flight-simulator applications. However, additional tests of display performance in high-speed flight simulation are required. A more rigorous test would involve ground target detection or identification during low altitude flight. In that case, terrain blur might also be a factor in that it may obscure even stationary ground targets.

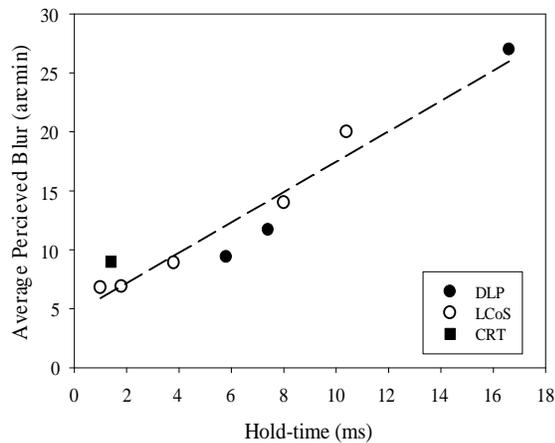


Figure 8. Average perceived moving-line blur as a function of hold-time for a CRT, a DLP with Accuframe, and a shuttered LCoS projector.

Shown in Figure 8 is gap width (i.e., perceived blur), measured using the moving-line stimuli, as a function of display hold-time. These data were obtained for a Barco 909 CRT, three hold-times for the Christie Matrix S+2k DLP, used in the present study, and for a shuttered LCoS projector from an earlier study (see Winterbottom, *et al.*, 2007). These data indicate that, display hold-time can be used to reliably predict perceived blur ($r = 0.963$, $p < 0.001$).

Shown in Figure 9 is a scatter plot of the perceived blur estimated from the roll-detection data of Figure 6, and the perceived blur estimated using the moving-line stimuli, each for the same set of speeds. These data show that the two measurements are highly correlated ($r = 0.82$, $p < 0.001$).

Shown in Figure 10 is the relationship between perceived blur obtained using the moving line test and proportion terrain blur from the pitch rate task,

each for the same set of speeds in deg/sec. Moving-line blur is highly correlated with perceived terrain blur resulting from the pitching motion ($r = 0.85$, $p < 0.001$). Thus the moving line test can also be used to predict the degree of terrain blur for motion over a flight database.

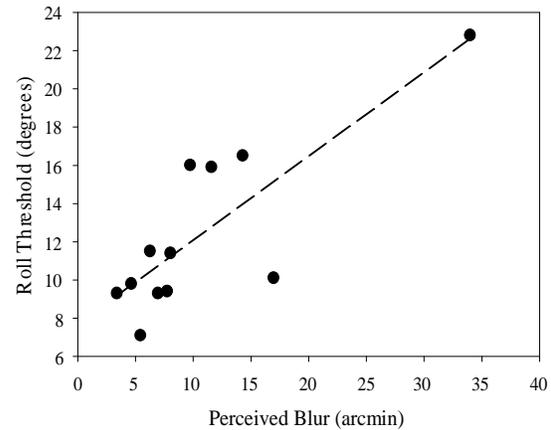


Figure 9. Perceived moving-line blur versus roll angle threshold.

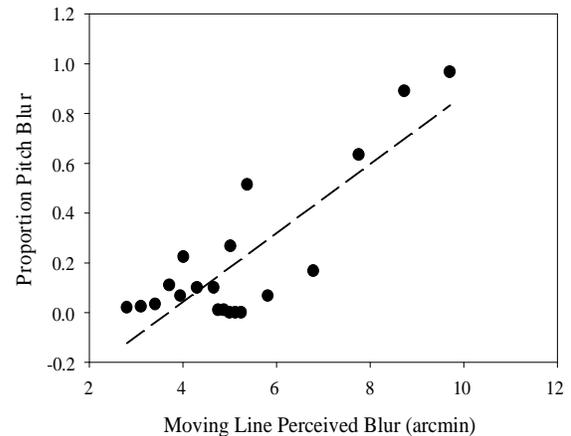


Figure 10. Proportion blur detection in the pitch rate task versus perceived blur with the moving line test for the same range of speed (6 to 10 deg/sec).

The correlations among the various variables represented in Figures 8 thru 10 suggest that either the 30 Hz test pattern or the simple moving-line test of display temporal resolution are valid predictors of image blur perceived during the performance of flight simulation tasks. These procedures have the added advantage that they are simple to administer and interpret, and do not require expensive equipment or software.

CONCLUSION

The present data show how moving image blur affects performance on tasks relevant to flight simulation and training. These data also show that digital-display hold-times of approximately 6 msec may be acceptable for fast-jet flight simulation, and that even a hold-time as high as 8 msec may be adequate for some tasks. Further, our results suggest that either a simple display response time measure or moving-line test is sufficient to predict both perceived blur and performance on flight tasks affected by blur. The simplicity of either measurement suggests that they may be useful as benchmarks for visual displays used in Air Force flight training and simulation.

ACKNOWLEDGMENTS

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