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Reducing Video Frame Rate Increases Remote Optimal Focus Time

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Summary

Twelve observers made best optical focus adjustments to a microscope whose high-resolution pattern was video monitored and displayed first on a National Television System Committee (NTSC) analog color monitor and second on a digitally compressed computer monitor screen at frame rates ranging (in six steps) from 1.5 to 30 frames per second (fps). This was done to determine whether reducing the frame rate affects the image focus. Reducing frame rate has been shown to be an effective and acceptable means of reducing transmission bandwidth of dynamic video imagery sent from Space Station Freedom (SSF) to ground scientists. Three responses were recorded per trial (time to complete the focus adjustment, number of changes of focus direction, subjective rating of final image quality). It was found that: (1) the average time to complete the focus setting increases from 4.5 sec at 30 fps to 7.9 sec at 1.5 fps (statistical probability = 1.2×10^{-7}); (2) there is no significant difference in the number of changes in the direction of focus adjustment across these frame rates; and (3) there is no significant change in subjectively determined final image quality across these frame rates. These data can be used to help pre-plan future remote optical-focus operations on SSF.

Introduction

This study was performed to gain an idea of the impact which relatively low video frame rates may have on focusing of optical systems such as cameras, microscopes, and telescopes remotely from ground during future Space Station Freedom science operations. It is part of a continuing effort to characterize and better understand various hardware, software, and human factors involved in remote video operations. For example, work has been performed in this laboratory on issues of video compression and frame rate on image acceptability to life scientists (Haines and Jackson, 1990; Haines and Chuang, 1992, respectively), and on the use of low-light-level, charge coupled device (CCD) video and infrared cameras to monitor the behavior and status of various living specimens in the dark (Chuang and Mian, 1992). Since transmission bandwidth to and from SSF will be limited, means must be found to reduce the transmitted bit rate wherever possible. Reducing video frame rate is one candidate method (Haines and Chuang, 1993).

Method

Procedure

Subjects were each given several practice sessions during which they sat with their eyes 76 in. (±2 in.) from a color

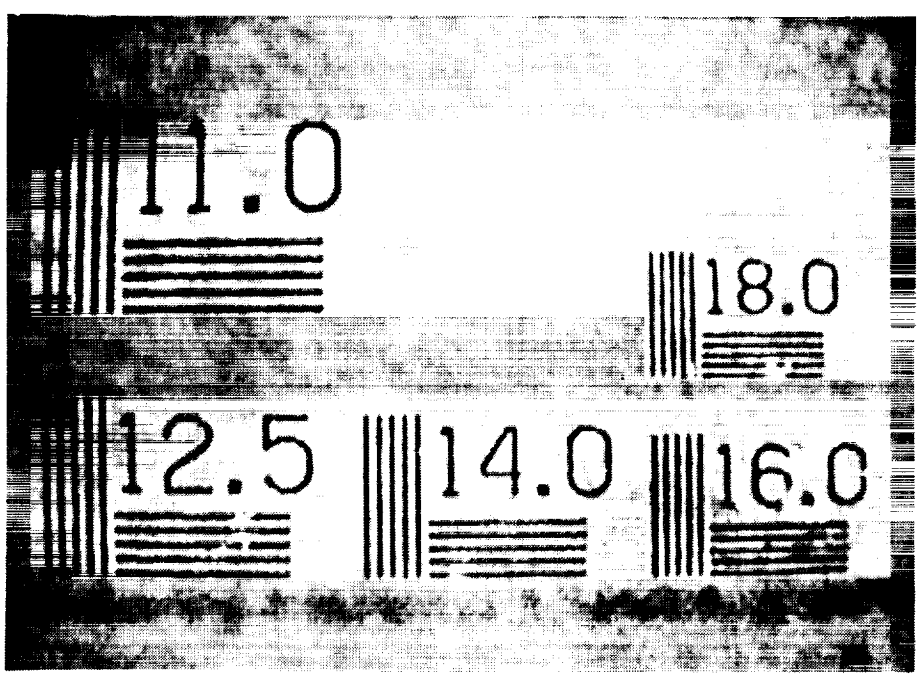

Figure 1. Parallel band resolution chart used.

television monitor that displayed the high-resolution pattern shown in figure 1. They were instructed to use the central pattern labeled 14.0 for their image-focus judgments. Image focus was emphasized as being of more importance than speed. Following this they made three focus settings, during which data were recorded. Before each trial the subject was asked to turn and look in another direction while the experimenter adjusted the focus to an out-of-focus image setting. The direction and amplitude of these "pre" focus settings were randomized. However, image blur was never great enough to yield a totally homogeneous gray screen. That is, the vertical and horizontal bars of figure 1 might appear to merge with each other, yet each group was still seen as a distinct vertical or horizontal area of darkness.

Following these three initial image-focus settings on the analog display screen, the subjects made all of the remaining focus adjustments while viewing a computer monitor located 26 in. (±1 in.) from their eyes. The subjects sat in front of a microscope–video-camera assembly and rotated the microscope's focus knob with their right hands.

Six randomly selected subjects were presented the 1.5-fps rate first followed by five progressively increasing frame rates; the other six subjects were presented the 30-fps rate first followed by progressively decreasing rates. The frame rates studied were 1.5 fps, 2.1 fps, 3.1 fps, 4.5 fps, 6.1 fps, and 30 fps.

The experimenter recorded both how long it took to complete each focus (to one second's accuracy) and the number of focus direction changes, and then made a subjective judgment of how good a focus was made. He used a four-point scale where: 1 = very poor focus (unusable image), 2 = barely usable focus, 3 = good but not perfect focus, and 4 = very sharp image focus. The experimenter (author) possesses corrected 20:18 acuity and is highly experienced in making such judgments. About 14 minutes were needed to make and record a complete set of 21 focus responses.

Apparatus

The apparatus consisted of a zoom microscope with the lens set to 60x, with a video color camera (Panasonic, CCD, WV-CD-132) attached to it by means of a specially designed transfer-optics assembly. Figure 2 is an equipment diagram. A high-resolution line pattern (Edmund Scientific Corp. No. 39857; NBS 1963A, positive-resolution target) was secured to the microscope stage. It was illuminated by a 50-W xenon shielded lamp located 13 in. away. The video signal was fed both to a 25-in. (diagonal) NEC color NTSC television monitor (model PR 2600A) and also to a 14-in. (diagonal) computer color monitor (IBM, type 8514-001) on which was displayed a 5.25-in. w × 3.75-in. h (256 × 240 pixels) window containing the compressed video image of the pattern at the same resolution. The video signal was routed to both displays by a Dynair video switch (model Dyna Mite, 10 × 10).

All digital imagery was compressed by an IBM PS/2 model 80-321 computer with an Intel "ActionMedia II" board set (ActionMedia II capture module; ActionMedia II delivery (daughter) board). IBM's multimedia software "Person-to-Person" was used in conjunction with the video-compression hardware. This application runs with OS/2's Presentation Manager, permitting live video to be displayed locally, remotely, or in videoconferencing mode. These video settings were used:

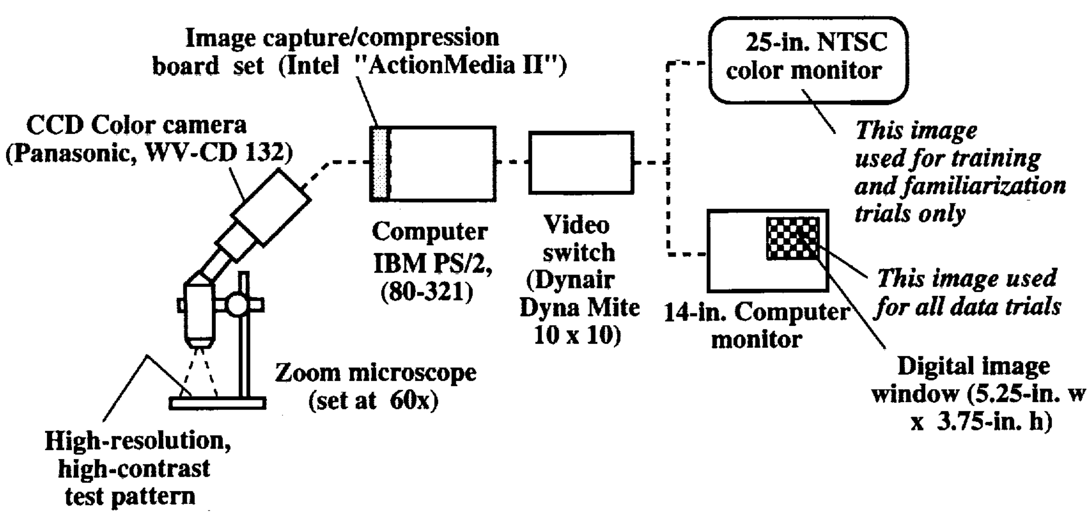

Figure 2. Diagram of hardware used.

tint = 50%; saturation = 76%; brightness = 66%; and contrast = 50%; effects = local; large view.

Subjects

Twelve people took part. Five possessed 20:20 or better uncorrected distance acuity. The others possessed 20:20 corrected distance acuity (four wore spectacles, two wore contact lenses, and one had had a radial keratotomy operation). Their ages ranged from 27 to 51 years (mean = 38).

Results

The findings are presented in four sections: (I) Time to Focus, (II) Number of Focus-Direction Changes, (III) Final Image Quality Ratings, and (IV) Analog Versus Digital Image-Focus Responses.

I. Time to Focus

Table 1 presents the mean and standard error of the mean, a measure of response variability. Each value is the mean of 36 responses. Note that the increase in focus time occurs monotonically below 6 fps.

All of the data were subjected to a one-way analysis of variance (ANOVA) with frame rate as the independent variable. It was found that the frame-rate main effect was statistically reliable ($F = 14.7$; $df = 5/210$; $P = 1.177 \times 10^{-7}$). These results provide strong support for the contention that the differences in focus times (ranging from 4.58 to 7.92 sec; see table 1) are not the result of chance but rather of these changes in frame rate.

Individual ANOVAs were run on all possible pairs of frame rates in order to determine between which frame-rate values the largest change in focus time occurred. These results are presented in table 2. The larger the "F" statistic value, the greater is the likelihood of statistical significance. The value labeled "Prob." in table 2

Table 1. Mean (SEM) time (sec) to complete microscope image-focus response as a function of video frame rate

Frame rate	Mean (sec)	(SEM) (sec)
1.5	7.92	0.51
2.1	6.19	0.38
3.1	5.61	0.34
4.5	4.86	0.20
6.1	4.49	0.19
30	4.58	0.17

Table 2. Individual ANOVA results on paired focus time data

	Frame rate (fps)						
	1.5	2.1	3.1	4.5	6.1	30	
1.5	—	0.99	5.81	12.2	11.6	9.19	F
		(ns)	0.02	0.0016	0.0020	0.004	Prob.
2.1	—	—	1.86	5.79	5.35	3.67	F
			(ns)	0.020	0.025	(ns)	Prob.
3.1	—	—	—	1.25	0.98	0.23	F
				(ns)	(ns)	(ns)	Prob.
4.5	—	—	—	—	0.038	0.842	F
					(ns)	(ns)	Prob.
6.1	—	—	—	—	—	0.537	F
						(ns)	Prob.

Notes: (ns) indicates not statistically significant at Prob. = 0.05 level.

represents a decimal representation of the probability that the same results would be obtained by chance alone if the same study were repeated many times. For example, a probability value of 0.02 indicates that if this study were repeated 100 times, one would expect to obtain the same findings only twice on the basis of chance factors. In such circumstances one is more justified in accepting that the results are from manipulation of the experimental variable (here, frame rate).

In table 2 it can be seen that the larger the difference between any two frame rates, the more likely it is that the focus-time difference will be statistically significant. Also note that there are no significant differences found for frame rates above 3.1.

Finally, it should be noted that each trial began with the focus knob already pre-set (by the experimenter) to some out-of-focus setting that varied by at least plus or minus one-half knob revolution; the total focus time includes this uncontrolled factor. It is likely that the same situation would occur during actual space operations.

II. Number of Focus-Direction Changes

It was of interest to know how many times these subjects changed the direction of focus on each test trial. Such information may be of value in determining the rate of wear on the servo-driven gear systems used (and replacement requirements) and for other reasons. Table 3 presents the minimum, mean, maximum, and standard error of the mean number of separate changes in focus direction. A one-way ANOVA conducted on these data

Table 3. Response data on the number of focus direction changes made

Frame rate	Minimum	Mean	Maximum	SEM
1.5	1	3.4	11	0.32
2.1	1	2.9	8	0.26
3.1	1	3.3	7	0.25
4.5	1	2.9	6	0.21
6.1	1	3.1	7	0.23
30	1	2.9	7	0.24

Grand mean = 3.1

showed that these values did not differ from one another sufficiently to be statistically significant.

A high degree of intersubject consistency was noted in this response measure. For example, one subject might adopt a personal strategy of rotating the focus knob very slowly in only *one direction* while another subject would rotate it more rapidly and *change directions* several times. Because of the relatively long screen-update delays produced at the lower frame rates, the second strategy did not work very well. Indeed, this was a major reason for conducting this study. These situations required these subjects to change and adopt the first strategy. It was discovered that only three of the twelve subjects accounted for all of the maximum values given in table 3.

Since the direction of initial focus offset was varied randomly from trial to trial (by the experimenter) there was a 50% chance that the subject would rotate the knob initially in the wrong direction and therefore need to change direction. It is for this reason that these mean values are biased, on the average, by one direction change half of the time. This same situation would be expected to occur in future SSF remote-focusing operations as well.

III. Final Image Quality Ratings

The experimenter used the four-point verbal scale described above to rate the goodness of final focus achieved for each trial's focus setting. A score of 4 indicates best focus. The following mean (SEM) values were found for these frame rates: 1.5 = 3.4 (0.10); 2.1 = 3.7 (0.08); 3.1 = 3.6 (0.09); 4.5 = 3.7 (0.08); 6.1 = 3.7 (0.08); and 30 = 3.6 (0.09). As expected, an ANOVA showed that these values did not differ significantly from each other.

IV. Analog Versus Digital Image-Focus Responses

It will be recalled that each subject made three focus adjustments while viewing a standard color (analog) television monitor and later another three while viewing a (digital) computer monitor, both displaying the identical test pattern at 30 fps. This comparison was included for study since the digital image was compressed; some compression algorithms add computational time so that this operation might possibly interact with the frame rate to influence user focus time. It was found that the mean (SEM) focus time for the television image was 4.64 (0.19) sec versus 4.44 (0.18) sec for the computer monitor, which was not statistically different.

Discussion

This study has shown that when a video image is compressed (using the commercial hardware and software described above) and frame rate is decreased progressively from its nominal (industry standard) value of 30 fps to 1.5 fps, viewers take significantly longer to make optical focus adjustments to achieve a subjectively determined "in focus" image. On the average, this effect appears to occur consistently below about 6 fps. It was noticed that the additional time to achieve best focus comes from a change in the viewer's response strategy wherein focusing is performed more slowly to permit the image to stabilize and become maximally clear before another (small) focus adjustment is made.

If reducing video frame rate is to be seriously considered as an approach to reduce transmission bandwidth to and from SSF, it must be shown empirically that image quality is not compromised in *any* way. A study dealing with reducing frame rate that was conducted using the same hardware as was used here involved remote video monitoring of small animals. It was found that frame rates as low as 1.5 fps were adequate (mean = 3.9 fps) for remotely determining the health and status of the animals (Haines and Chuang, 1993). More research is called for, however, using a broader array of representative SSF science requirements to verify that reducing frame rate will not compromise other science procedures.

Whether or not the lengthened ground-crew optical focus response found here will adversely impact actual operations on SSF will depend upon such factors as the allotted time to carry out the optical procedures, the number of times an image must be refocused, and the transmission delay (which is over and above the present frame-rate-related delay). If a particular science procedure requires viewing each of 50 samples in sequence, for instance, and a frame rate of 2.1 fps is used rather than 30 fps, 1.34 minutes will be added to the total procedure time; a 1.5-fps rate will add an additional 2.8 minutes just to perform all manual focus responses. If time is a major operational consideration along with transmission bandwidth, the addition of a video autofocus capability should be considered.

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