Television Image Compression and Small Animal Remote Monitoring

Richard F. Haines
Robert W. Jackson

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Richard F. Haines
Research Institute for Advanced Computer Science
Ames Research Center - NASA

Robert W. Jackson
Pioneer Missions Office
Ames Research Center - NASA

ABSTRACT

Thirty four subjects viewed thirty second-long segments of compressed television imagery of small animals inside small enclosures representative of those planned for use in the Space Station Freedom (SSF). Their task was to make ratings of image quality and overall acceptability as if they were remotely monitoring the animals from the ground. Each scene was compressed to six levels ranging from 384 to 1,536 kilobits per second and presented in random order. Image quality was rated using a seven point scale under four test conditions: (1) stable camera (on tripod) with rats relatively quiescent (lights on) and (2) with rats relatively active (lights dim), (3) moving (hand-held) camera with rats quiescent (lights on) and (4) stable camera (on tripod) with rats relatively active (lights dim). Both moving camera conditions (quiescent and active animals) produced significantly improved judged image quality with decreased levels of compression ($p = .0001$). A similar smaller trend was noted for the stable camera condition when the animals were quiescent (lights on) ($p = .02$). No such trend was found for the stable camera condition where animals were more active (lights dim). Each scene was also rated for overall image acceptability to support remote visual judgments of the animals' health and status. A score of 1 = acceptable image and 2 = unacceptable image. It was found that: (1) an acceptably clear video image was associated with transmission rates above 768 kbits per second for the moving camera, quiescent animal condition. The mean acceptability score was 1.7 for the 768, 1.4 for the 1,152, and 1.2 for the 1,536 kbit per sec video compression conditions. (2) when the camera was stabilized and the animals were quiescent most subjects rated the imagery as acceptable across all six of the compression levels (mean = 1.3). (3) the condition where the animals were active and the camera was stable resulted in no change in image acceptability across the six compression levels (mean = 1.5). (4) the mean acceptability rating varied almost linearly from 1.8 (384 kbits per sec) to 1.32 (1,536 kbits per sec) for the moving camera and quiescent animal condition. Clearly, maintaining a fixed camera more than pays in terms of making optimal use of available bandwidth. These findings may find use in planning for future Space Station Freedom video transmission characteristics.

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INTRODUCTION

A major challenge in future Space Station Freedom (SSF) planning and science operations support will be to meet engineering and scheduling requirements while also providing the life scientist (and others) with enough flexibility of execution that they can respond to new and unanticipated opportunities for data collection and analysis *during the mission*. Carefully planned teleoperations can help meet these challenges. Real time modification of an experiment's design "...to reflect the latest research findings, including those obtained on the same flight" are likely to lead to greatly enhanced scientific productivity (Anon., 1987). Nevertheless, currently planned space to ground transmission bandwidth imposes serious limitations on the amount of information that can be transmitted. There may well not be enough bandwidth to permit each ground investigator to gain real time access to his or her equipment on SSF to support real time "quick looks" and manipulation of the space hardware and incoming data. This concern forms the basis for the present study.

Current plans for digital information and video imagery transmission to and from SSF require that all signals be relayed via the Tracking and Data Relay Satellite (TDRSS). Maximum bandwidth from the Ku band of TDRSS is somewhat under 220 Mega bits per second (footnote 1). Due to the large number of science activities planned for SSF as well as the need for on-going safety and utilities monitoring it will be necessary not only to carefully schedule all down-link transmissions but also to reduce total bandwidth requirements to an absolute minimum from each activity on SSF. This investigation addressed the second issue as regards video imagery transmission.

There is relatively little in print regarding the practical impact of different levels of video compression on subjective judgments of the quality or usefulness of the imagery which results. As Haskell and Steele (1981) state, "Only when perception is properly understood will we have accurate objective measures. However the day when we can, with confidence, objectively evaluate a *new* impairment without recourse to subjective testing seems very remote." With regard to requirements to support video teleconferencing Ohira et al. (1978) reported that about six megabits per second rate is suitable for teleconferencing (assuming a Hadamard/slant transform and color). Eng and Haskell (1981) found that 1.5 megabits per second rate was acceptable for black and white teleconferencing as long as an unspecified reduced temporal and spatial resolution could be accepted. Others suggest that eleven megabits per second is suitable for teleconferencing (Hadamard transform, cf. Gonzalez and Wintz, 1987) for a black and white image. So called network picture quality was found to be supported by bit rates ranging from 22 to 86 megabits per second, depending upon required level of visual resolution (Golding, 1972). Clearly there is little agreement not only on this subject but also on *how image degradations should be quantified.*

Two other studies were conducted which addressed several somewhat related issues, viz., trade-offs between video resolution level, bit rate, and grey scale as related to future aerospace operations. Ranadive (1979) found that video bandwidth was directly proportional to the product of *resolution* (ht. x width; pixels per frame), *frame rate* (frames/sec.), and *gray scale* (bits/pixel). When the user varied one of these three parameters at a time while watching his own motions and attempting to control a robot performing a simple task, it was found that he could carry out the assigned tasks relatively well even though the image was degraded significantly. All subjects were trained to asymptotic levels of proficiency before data was collected. Performance was defined as the quotient Tt/Td where Tt is the time to accomplish the task using full video (no degradation) and Td is the time required to accomplish the task using degraded video. Thus, as long as only one of the three parameters was degraded performance was still acceptable down to a point where the task could not be accomplished at all. He also found that frame rate and gray scale could be degraded by larger amounts than resolution before the critical performance limit was reached. One interesting implication of this work is that the viewer may be able to carry out required tasks with significantly less video bandwidth than formerly thought. Nevertheless, relatively little has been done to quantify this matter.

For the manual control tasks used by Ranadive, the limiting parameters were:

Resolution: 64 x 64 pixels @ 28 frames/sec @ 4 bits/pixel
Frame Rate: 3 frames/sec @ 128 x 128 pixels @ 4 bits/pixel
Gray Scale: 1 bit/pixel @ (28 frames/sec @ 128 x 128 pixels)
(values in parenthesis are assumed since they were not stated explicitly)

In a second investigation conducted at MIT an operator was permitted to adjust resolution, frame rate, and gray scale during manual robotic control operations under total bit rate constraints (Deghuee, 1980). Dynamically changing these three parameters in real time influenced performance although lower bit rates did not result in reduced performance. Since only two bit rates were studied (10K and 20K) it is possible that these bit rate conditions were not sufficiently different from one another to produce significant decrements in performance. Deghuee also noted that the operators did not adjust the three parameters to achieve an image with some "optimal" quality but, rather, set each parameter to achieve some predetermined combination of settings of the three available parameters. This study showed that the type of manipulation task undertaken yielded the most significant differences in performance. It is fair to say that with an increase in the number of compression algorithms comes an increase in the kinds of perceived image degradations. Until we understand human perception much better subjective measurement of image quality will continue to be needed (cf. Watson, 1987; Watson et al., 1983).

A question of interest is whether use of higher resolutions (e.g., 400+ x 400+ pixels), frame rate (60 Hz), and color will produce a similar equivalency in trade-offs as was found by Ranadive. The present study addressed the related matter of reduced total bit rate upon judged image acceptability and quality using a rating scale having verbally defined anchor points with which the viewer can evaluate the image.

The present experiment was conducted to explore the degree of image degradation associated with various levels of video image compression ranging from the T-1 standard (1.54 megabits per second) to one-fourth of T-1 (384 kilobits per second). Three experimental variables were of interest: video *transmission bit rate* resulting from a specific image compression technique, *animal activity level (active and quiescent)*, and *camera motion (stable and hand-held)*. Image motion is the major determiner of image quality during video compression since the algorithm used (typically) acts only on those pixels that do not change. Animal activity level was varied by means of video taping animal activity in lighted room conditions during that part of the diurnal cycle when they are normally quiescent (asleep) and also during the nocturnal period (approximately twelve hours later) when they are normally active. A moving camera condition was included to be able to compare image quality when all pixels changed, as occurs during hand-held video taping, versus when only those pixels containing the moving animals changed.

METHOD

The method is described in the following four sections, procedural tasks, experimental design, apparatus, and test subjects.

Procedural Tasks. Each subject (S) was given a pencil and paper scoring form (Appendix A) and asked to sit about five feet from a medium resolution color TV monitor (400+ lines) on which all imagery was presented. Groups of from three to ten Ss were tested together. A pre-test image evaluation criteria form was administered to enable post-test response data evaluations. It was explained that each S was to pretend that he or she was an experimenter on the ground conducting a remote study on SSF that involved small white rats. One of their tasks was to monitor the overall health and status of these animals using video. S was then presented a practice session in which each of the six video compression levels were presented in order for about 20 seconds; they were told in advance what level of video compression was being presented in each scene. This permitted them to associate each level of compression with its resulting visual effect. Questions were answered until it was clear that everyone understood the required tasks. The first of the four test conditions followed immediately, during which S rated the image quality of each of the six, randomly selected compressed video scenes using the scoring form. S also judged whether or not the image was of acceptable or unacceptable quality to be able to judge the health and status of the animals.

A seven point rating scale was used ranging from 1 = "completely unacceptable image clarity," to 7 = "maximally clear/undistorted image clarity." Each rating number was clearly defined. Subjective comments and other observations also could be made. At no time did S know what condition would appear next. The other three test conditions were presented as above but with different random orders of video compression. Total test time was about 18 minutes with a brief rest break given between each of the four test conditions.

A viewing duration of about 30 seconds per compressed scene was used to help limit the impact which observer cognitive reflection might have on response variability; e.g., longer viewing times might encourage S to over-evaluate each image or to otherwise introduce personal biases. We sought more of a "first impression" evaluation, hopefully one based on a small number of personal evaluation criteria.

For the two stable camera conditions the camera was mounted on a tripod and aimed downward at the three animal cages positioned side by side on the floor. A sheet of clear plexiglass covered the open-topped cages. This afforded an unobstructed view of all animal behavior. During this condition the only image motion was produced by the seven small rats inside their enclosures.

During the moving camera condition an experimenter held the camera on his shoulder while standing near the cages. The camera was aimed at about the same location as above and was at the same separation distance (about 48 inches) from the nearest end of the animal cages. The experimenter practiced so that the rate and amplitude of image motions were approximately the same between the two moving camera test conditions. Small amplitude whole-image motion resulted which severely degraded the displayed images as a function of video compression level. Image fragmentation was particularly apparent under the highly compressed lights on condition. The same 30 sec-long scene within each of the four test conditions was subjected to video compression to help reduce within-test-condition sources of response variance.

Experimental Design. The study may be described as a subject by randomized treatments design with six levels of video compression (384, 448, 576, 768, 1152, and 1536 kilobits per second) embedded within the two levels of camera motion and two levels of animal motion. Thus, each S viewed 24 scenes. A primary objective of using this design was to collect parametric data that could be subjected to statistical analyses to yield reliability estimates for the data and to be able to extrapolate the data to a wider range of applied situations.

Apparatus. The apparatus consisted of an RCA model CC350, SVHS color camcorder to record the animals, cages, etc. This camcorder was also connected (later) to a 19" NEC model PR2000S color monitor possessing National Television Systems Committee (NTSC) broadcast resolution of approximately 400+ lines (vertical) to present the imagery to the groups of Ss. In order to vary video compression level, a Compression Labs. Inc. (CLI) Rembrant model was used. This device employs a proprietary algorithm for compressing all nonchanging pixel imagery. It was found in preliminary tests that image quality was significantly degraded when the camera moved relative to the scene. In such instances each screen pixel is subjected to the compression computations.

The seven small (approx. 7" long) white rats used remained within metal cages designed, built for, and flown on NASA's Space Lab 3 mission. Each cage measured about 4.5" wide x 6" high x 22" long and was constructed of aluminum. Its hinged lid was left open and covered with a plexiglass sheet.

Cage lighting was achieved by means of the normal animal holding facility (100 watt incandescent) ceiling light for the light on condition for 12 hours each day (from 8 am to 8 pm). When these lights were automatically turned off (from 8:01 pm to 7:59 am) a dim incandescent floodlight evenly illuminated the cages (approx. 15 ftc).

Subjects. Thirty four subjects (Ss) took part. Twenty two were males and twelve were females. All were NASA employees or contractors at Ames and were between the ages of 23 and 64 years (mean = 38.6 yrs.). Thirteen Ss (mean age = 41.1) (7 males; 6 females) were very familiar with small animal behavior being animal handlers, trainers, physiologists, biologists, etc. Twenty one Ss (mean age = 37.7) (15 males; 6 females) were not. Both the age range and mean age of the males was similar to that of the females. All possessed 20:20 or better visual acuity. Approximately half of the Ss wore glasses to correct their vision.

RESULTS

The results are presented in three sections. The first deals with the mean subjective rating results of overall image quality. The second deals with judgments of image acceptability or unacceptability. Section three presents a summary of the image evaluation criteria responses which each S provided before testing started.

Subjective Rating Results:

These rating data were subjected to a three factor, factorial model analysis of variance with the six video compression levels nested within the other four test conditions. Table 1 presents the findings. It may be noted that the moving camera condition produced the highest and most consistent image quality ratings. The overall within Ss treatment main effect was statistically significant (F = 29.4; df = 23/767; P = .0001) as was the between Ss effect (F = 3.6; df = 31/767; P = .0001). What this means is that the improvement in image quality with decrease in compression level (for these three test conditions) is very likely not due to chance but to a genuine effect of these variables. None of the two- or three-way interactions was significant.

Table 1

Analysis of Variance Results

Test Condition	d/f	F	P
Stable Camera, Quiescent Animals (Lights On)	5/203	2.75	0.020
Stable Camera, Active Animals (Lights Dim)	—	—	n.s.
Moving Camera, Quiescent Animals (Lights On)	5/197	98.7	0.0001
Moving Camera, Active Animals (Lights Dim)	5/191	20.6	0.0001

Figure 1 presents the mean (S.D.) image quality rating results separately for each of the four test conditions. Video test condition is rank ordered, increasing from left to right in each graph as is shown. Table 2 presents these data in digital form. A score of two refers to "very much below average image clarity", a score of three refers to "below average image clarity, and a score of four refers to "average image clarity. "The mean acceptable image clarity rating across these six video compression levels is significantly higher for the static camera condition (Grand mean = 3.52) than for the moving camera conditions (Grand mean = 2.74). Nevertheless, the highest mean score, associated with a T-1 compression level, was only a four which refers to "average image clarity." The level of animal activity did not yield as large a difference in judgments. The grand mean rating for the active animal (lights dim) condition was 3.02 while the grand mean rating for the quiescent animal (lights on) condition was 3.24 on the scale from one to seven.

Figure 1a

Mean Rating Results for Stable Camera, Quiescent Animals (Lights On) Condition

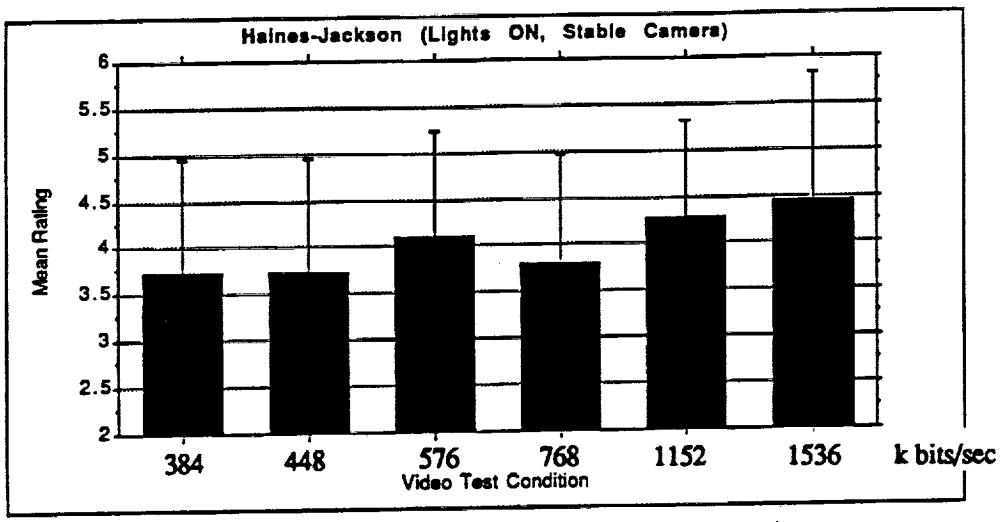


Figure 1b

Mean Rating Results for Stable Camera, Active Animals (Lights Dim) Condition

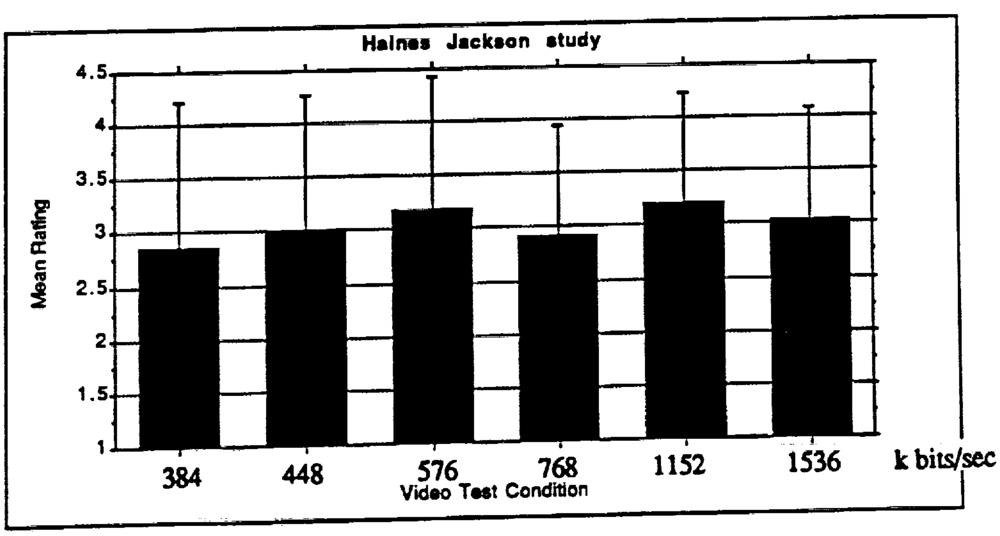


Figure 1c

Mean Rating Results for Moving Camera, Quiescent Animals (Lights On) Condition

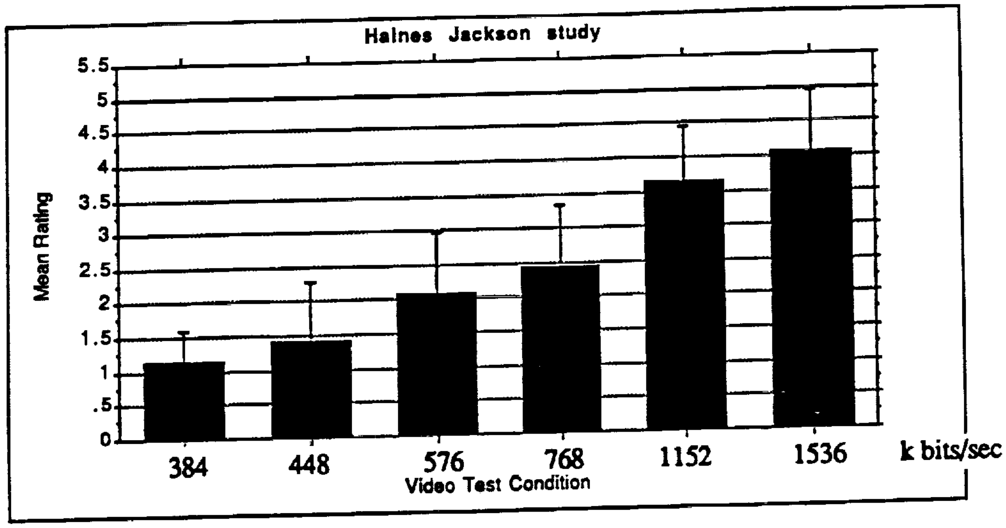


Figure 1d

Mean Rating Results for Moving Camera, Active Animals (Lights Dim) Condition

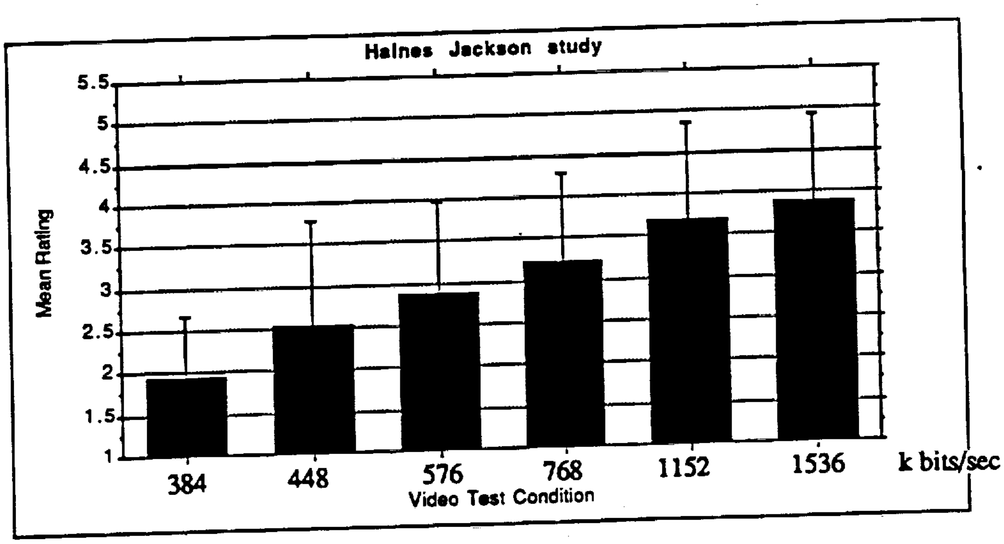


Table 2

Mean Subjective Image Quality
Rating Results
(N = 34)

Animals Relatively Quiescent (Lights On)

	Static Camera						Moving Camera					
bit rate (kbps)	384	448	576	768	1152	1536	384	448	576	768	1152	1536
Mean Rating	3.7	3.7	4.1	3.8	4.3	4.4	1.2	1.4	2.1	2.4	3.6	4.1
S.D.	1.2	1.2	1.1	1.2	1.1	1.4	0.4	0.9	0.9	0.9	0.8	0.9

Animals More Active (Lights Dim)

	Static Camera						Moving Camera					
	384	448	576	768	1152	1536	384	448	576	768	1152	1536
Mean Rating	2.9	3.0	3.2	2.9	3.2	3.0	1.9	2.5	2.9	3.2	3.7	3.9
S.D.	1.4	1.3	1.2	1.0	1.0	1.1	0.7	1.2	1.1	1.1	1.2	1.1

A comparison was also made between the mean ratings of those Ss who were familiar with small animal behavior (e.g., animal physiologists, animal trainers and keepers, animal health technicians, veterinarian) and those were not (e.g., computer scientists, engineers, psychologists, botanists, architects). Almost identical mean rating data was obtained from each group for three of the four test conditions. This is not difficult to understand since both groups possess the same overall visual capabilities and are (likely) observing the same general animal motions. The only test condition to yield a small difference was the stable camera, quiescent animal condition where Ss familiar with small animal behavior gave (non significant) higher ratings than those who were not (mean = 4.03 vs. 3.18, respectively). This could be due to the fact that the lights on condition made it easier for this group to identify subtle animal behavior which the other S group were not looking for. Another comparison of mean ratings was made between the male and female Ss. No significant differences were noted.

Image Acceptability Judgment Results:

Immediately following each subjective image quality rating S also had to indicate whether he thought the image was acceptable or unacceptable in terms of being able to judge the overall health and status of the animals. These ratings were tallied for each test condition across all Ss. An acceptable rating was scored as 1 and unacceptable as 2. The mean results are presented for each test condition in Figure 2 and Table 3. Since a binary scale was used, these mean data are directly related to the percentage of all Ss who scored the image as being acceptable or unacceptable. As in Figure 1, compression level decreases from left to right on the X axis in the same steps. It can be seen that, in general, the less the compression the higher the acceptability of the image (cf. Figure 2c and 2d), both of which involve the moving camera. Use of the binary rating scale precluded use of parametric statistical treatment.

Figure 2a

Mean Acceptance Rating Results for Stable Camera, Quiescent Animals (Lights On) Condition

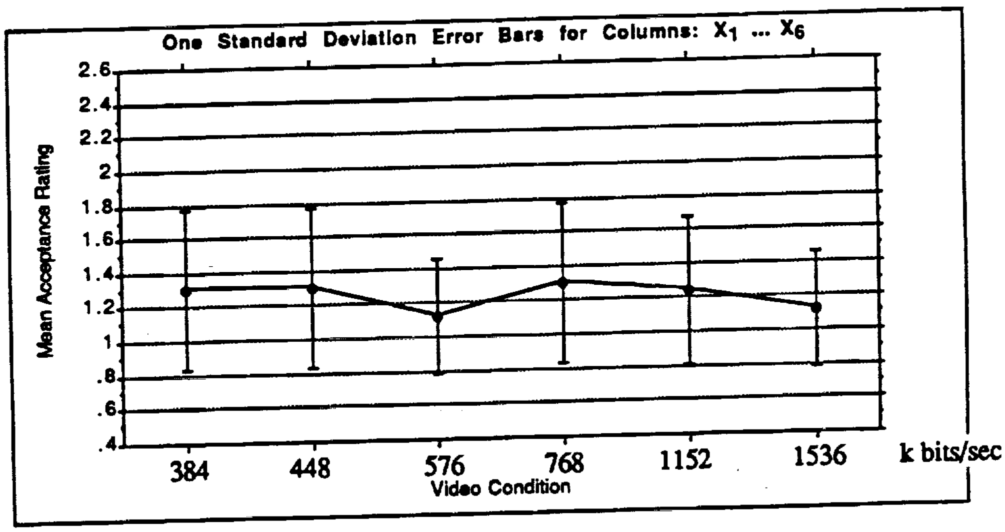


Figure 2b

Mean Acceptance Rating Results for Stable Camera, Active Animals (Lights Dim) Condition

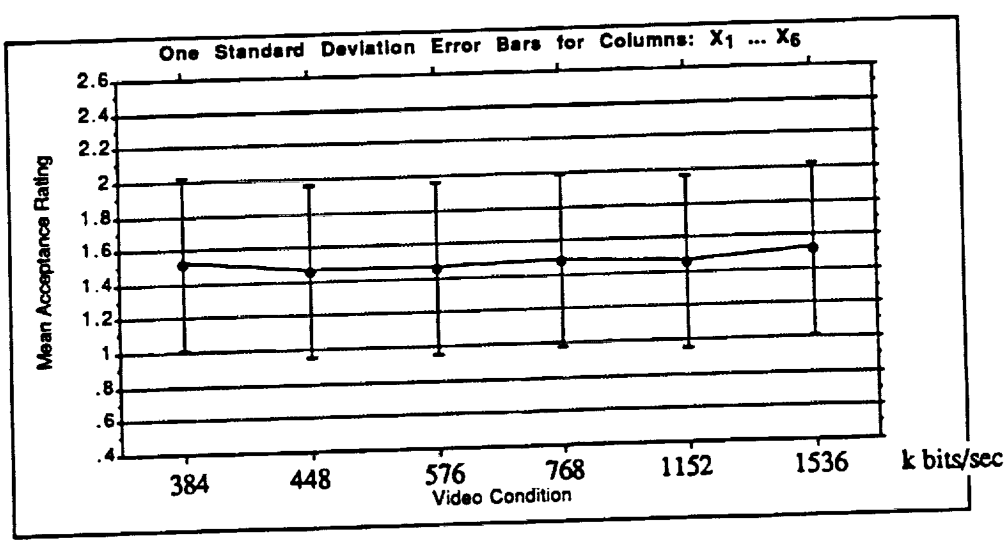


Figure 2c

Mean Acceptance Rating Results for Moving Camera,
Quiescent Animals (Lights On) Condition

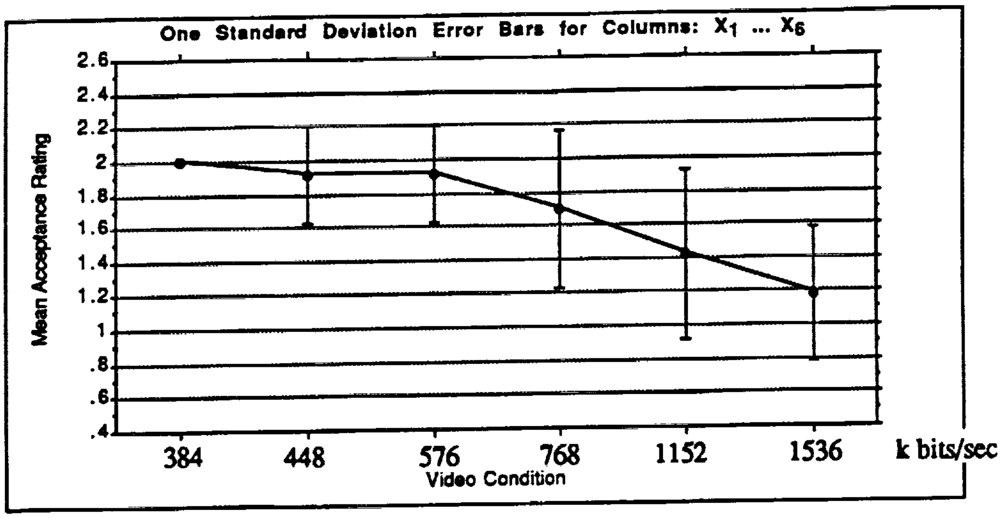
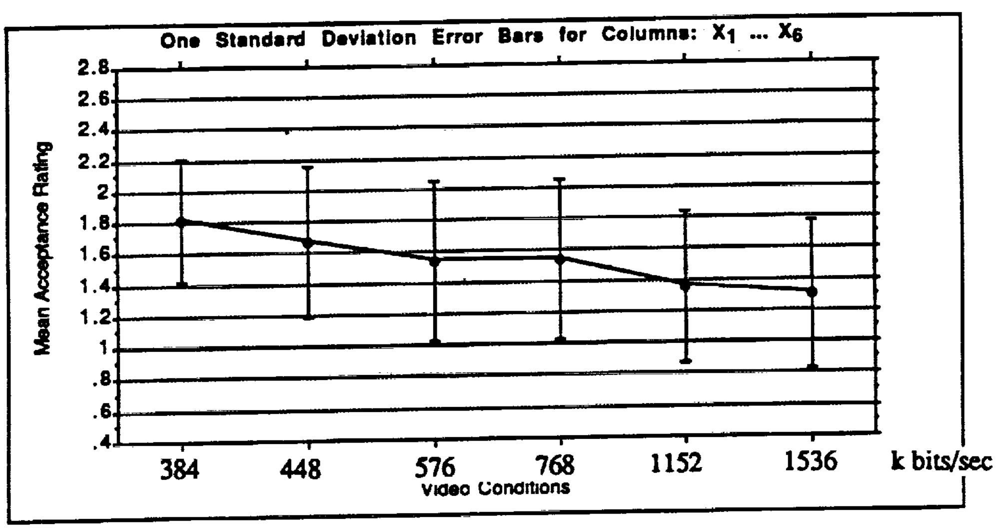


Figure 2d

Mean Acceptance Rating Results for Moving Camera,
Active Animals (Lights Dim) Condition



Referring to Figure 2c (moving camera, quiescent animals) it may be noted that the three highest compression levels (384, 448, and 576 kbits per sec) produced unacceptable images. The other levels of compression yielded a linear improvement in acceptability reaching a maximum mean value of 1.19 for the T-1 transmission rate. When the animals were more active imum mean value of 1.19 for the T-1 transmission rate. When the animals were more active and the camera was moving (Figure 2d), an approximately linear relationship was found ranging from a mean of 1.8 for 384 kbits per sec to 1.32 for the T-1 transmission rate condition. One interpretation of this finding is that the dim lighting condition made it more difficult to see small movements of the animals and this difficulty was reflected in a smaller range of mean acceptability judgements than found for the Figure 2c data.

Table 3

Mean Image Acceptability Results:
(A) Animals Relatively Quiescent (Lights On)

	Static Camera						Moving Camera					
kb/sec	384	448	576	768	1152	1536	384	448	576	768	1152	1536
Mean Rating	1.3	1.3	1.1	1.3	1.2	1.1	2.0	1.9	1.9	1.7	1.4	1.2
S.D.	0.5	0.5	0.3	0.5	0.4	0.3	0	0.3	0.3	0.5	0.5	0.4

(B) Animals More Active (Lights Dim)

	Static Camera						Moving Camera					
kb/sec	384	448	576	768	1152	1536	384	448	576	768	1152	1536
Mean Rating	1.5	1.5	1.5	1.5	1.5	1.5	1.8	1.7	1.5	1.5	1.4	1.3
S.D.	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.5	0.5

A comparison was made between the image acceptability judgments of the Ss who were more familiar with small animal behavior and those who were not. No clear cut differences were found. Similarly, no differences in mean rating were found between male and female Ss.

Pre-Test Image Evaluation Criteria:

Each S was asked a number of questions before the test began to gain a better idea of what particular image features were important to them. Several other questions were also asked. The presumption was made that these subjective criteria would be involved in making scene judgments. All 34 Ss felt that it would be useful to have a closed circuit TV capability for their SSF activity. Table 4 presents these findings. It is apparent that (1) The great maportant image features, regardless of whether or not they had prior experience working with small animals. (2) There was a somewhat larger divergence of opinion as to whether color was needed in order to conduct their research. (3) Most Ss indicated that they felt it was important to have alpha/numerics visible on the screen (not necessarily continuously), and (4) More of those who do not work with animals had seen high definition TV prior to this study.

Table 4

Pre-Test Image Evaluation Criteria Results
(Number indicates number of respondents)

		Prior Experience Working with Animals?	
Question	Answer	Yes (N = 13)	No (N = 21)
Importance of Image Clarity?	Very Important	8	9
	Important	5	10
	Not Important	0	1
	No Answer	0	1
Importance of Image Movement?	Very Important	7	7
	Important	3	9
	Not very important	3	2
	No Answer	0	3
Importance of Image Color?	Very Important	4	3
	Important	5	11
	Not Important	3	5
	No Answer	1	2
Importance to be able Read Alpha/Numerics?	Yes	12	18
	No	1	2
	No Answer	0	1
Have You Ever Seen High Definition TV?	Yes	1	7
	No	12	14

DISCUSSION

This study has shown that Ss can reliably discriminate a difference in video image quality (using a specific commercial product) for compression levels ranging from 384 kbits per sec to 1,536 kbits per second but that their discriminations are significantly influenced by whether or not the TV camera is stable or moving and whether or not the animals are quiescent or active which is correlated with illumination level (daytime versus night illumination, respectively).

The highest video rate used here was 1.54 megabits per second which is about 18 percent of the so-called normal TV resolution of 8.4MHz. Since this video rate was judged to be acceptable by 27 of the 34 Ss (79 percent), for monitoring the general health and status of small animals within their illuminated (lights on) cages (regardless of whether the camera was stable or moved), it suggests that an immediate SSF to ground video bandwidth reduction by about 80 percent can be tolerated without a significant loss in general monitoring capability. Another general conclusion is that the present methodology appears to be effective in quantifying visual judgments of video image quality.

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FOOTNOTES

1. The maximum available Ku band downlink from the TDRSS system is 300 mega bits per second. From this must be subtracted bandwidth associated with (a) various overhead functions such as headers, forward error correction, synchronization (14%), and (b) SSF core support requirements such as data status and audio (1.6%). This reduces the available bandwidth to the user to about 253 mega bits per second from which another 14% must be subtracted to account for the orbital zone of exclusion (approx. 13 minutes per orbit) for an average available bandwidth of 218 Mbps. (Reference: Work Package 2 User Integration (UI) Role for DMS and C&T Systems Design, McDonnell Douglas, Report MDSSC-SSD, June 1989.

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Appendix A

Pre Test Data Form

Experiment 2-A

Print Your Name: ____________________

Today's Date: ______________

Present Occupation/Title: ____

Age: _____ Sex: ________ Academic Specialty? ____________________________

Assuming that you are a PI on the ground and your small animal experiment is being conducted on Space Station Freedom by a Mission Specialist, please answer the following questions:

1. Would you be able to use closed circuit TV (CCTV) in your study? ______________

   Comments/Explanations: ____

2. If your experiment requires CCTV how would you use it?______________________

   ____

3. How important would TV image *clarity/resolution* be to your experiment?___________

   ____

4. How important would TV image *movement discrimination* be?__________________

   ____

5. How important would TV image *color* be? _________________________________

   ____

6. Have you ever seen high definition TV? _________ When? ____________________

7. Is it important for you to be able to read TV screen alpha-numeric information using CCTV? __________ Why not? ______________________________________

Experiment 2-A

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Image Quality Rating Form

Name: ______________________

Date: ____________ Time: ____________

Please use the following numeric rating scale for each of the video scenes you will be shown. Place the number you select in the space provided at the left side of each space. Give primary emphasis to image clarity as it relates to your own science discipline requirements. Also indicate if the image quality was acceptable or unacceptable to you.

1	*2*	*3*	*4*	*5*	*6*	*7*
Completely Unacceptable Image Clarity	*Very Much Below*	*Below Average Image Clarity*	*Average Image Clarity*	*Above Average Image Clarity*	*Very Much Above*	*Maximally Clear/Undistorted Image Clarity*

(A) ***Lights ON, Stable Camera***

Insert Your Score below	Run No.		Is Image Quality Acceptable? *(yes, no)*	Explain what image features were important to you in making each rating judgment.
	1			
	2			
	3			
	4			
	5			
	6			

(B) ***Lights OFF, Hand-Held Camera***

	1			
	2			
	3			

Score Here		Image Quality Acceptable?		What image features were important to you in making each rating judgment?
	4			
	5			
	6			

(C) Lights OFF, Stable Camera

	1			
	2			
	3			
	4			
	5			
	6			

(D) Lights ON, Hand-Held Camera

	1			
	2			
	3			
	4			