NASA Technical Memorandum 103976

Dark-Cycle Monitoring of Biological Subjects on Space Station Freedom

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Summary

The operational environment for biological research on Space Station Freedom will incorporate video technology for monitoring plant and animal subjects. The video coverage must include dark-cycle monitoring because early experiments will use rodents that are nocturnal and therefore most active during the dark part of the daily cycle. Scientific requirements for monitoring during the dark cycle are exacting. Infrared (IR) or near-IR sensors are required. The trade-offs between these two types of sensors are based on engineering constraints, sensitivity spectra, and the quality of imagery possible from each type. This paper presents results of a study conducted by the Biological Flight Research Projects Office in conjunction with the Spacecraft Data Systems Branch at Ames Research Center to investigate the use of charged-coupled-device and IR cameras to meet the scientific requirements. Also examined is the effect of low levels of near-IR illumination on the circadian rhythm in rats.

Introduction

The Biological Flight Research Projects Office (BFRPO) at Ames Research Center is developing a facility on Space Station Freedom (SSF) for controlled-gravity life sciences investigations that involve plant and animal subjects. The facility will house a variable-gravity centrifuge, two habitat holding units, a glove box, and a service system, as shown in figure 1. The centrifuge will create gravity fields ranging from 0.01 g to 2.0 g. The habitat holding units will hold several plant and animal habitats at microgravity conditions. Both the holding units and the centrifuge will provide support services to the habitats, including air, power, cooling fluids, waste handling, contamination control, data systems, and video. The BFRPO concluded concept-design studies in 1992. It is planning to initiate design, development, and testing of the flight hardware in 1993, with a target of 1998/99 for initial launch of the facility (ref. 1).

The centrifuge accommodates four plant habitats or eight animal habitats, and each holding unit also accommodates four plant habitats or eight animal habitats or combinations thereof. Each modular habitat will house the experimental subject(s) and the associated camera equipment to provide video monitoring capabilities. Video monitoring of the subjects within each habitat is required on a 24-hour basis. Each habitat will be equipped with a maximum of three video cameras for day-cycle monitoring and three cameras for the dark cycle. The total number of operational cameras within the facility at any one time can exceed 72. The facility has many engineering constraints such as power, weight, and physical size that must be considered in the selection of an appropriate camera system.

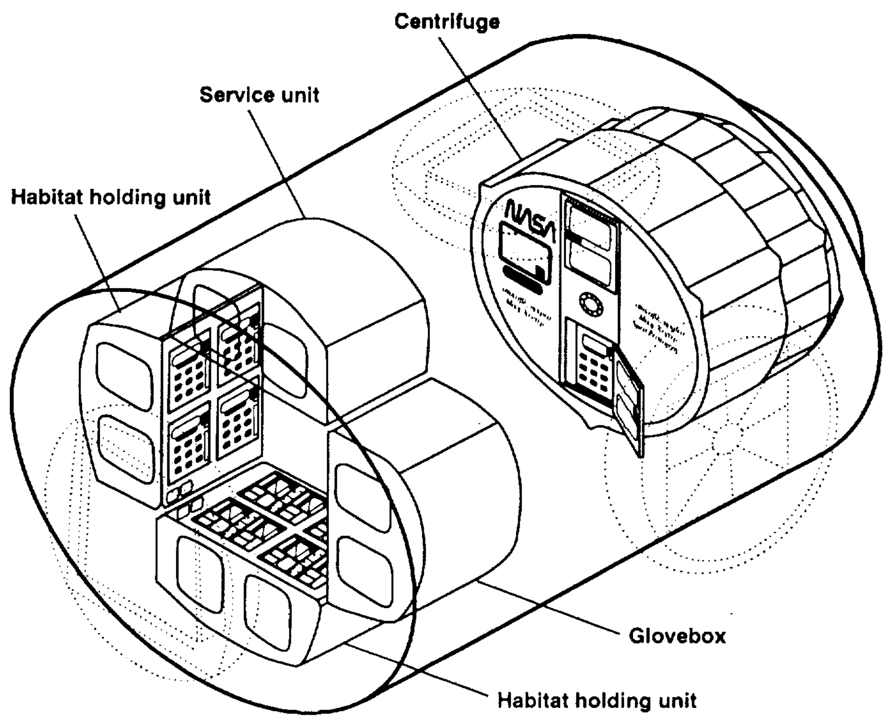

Figure 1. Biological flight research facility.

A seemingly obvious solution to providing the dark-cycle monitoring capability is the use of infrared (IR) sensors. However, the utilization of IR cameras is not favored in the habitats because of weight, volume, power, and other engineering considerations. A thumb-size charged-coupled-device (CCD) monochrome camera is considered as an alternate. The CCD camera can detect near-IR wavelengths within the range of 0.75–1.0 µm. This paper introduces the CCD technology, compares engineering trade-offs with conventional IR technologies, evaluates resultant video imagery from both technologies, and provides evidence that the near-IR lighting required for this camera will not affect the physiology of subjects of interest.

Scientific Requirements

The space life sciences community requires comprehensive video capability in order to monitor the behavior, activity, growth, and health of on-board subjects. The viewing requirements range from one image every few minutes for a plant subject to four hours of continuous motion video several times per day for a rodent subject.

During the dark cycle, near-perfect darkness must be maintained. The plants demonstrate phototropic response in selective regions of the visible spectrum up to approximately 0.8 µm wavelengths. Any illumination of the animal subjects can potentially affect a variety of physiological systems such as circadian rhythms, dermal physiology, and neuroendocrine systems (ref. 2). The effects of near-IR photic inputs to animal systems are still not well understood. The manner in which specific wavelengths and intensities affect the physiological systems of the different species still needs to be determined.

The lack of concrete scientific data has called for stringent near-IR illumination constraints and the use of passive IR monitoring. In this case, the subject must be kept in complete darkness, and video viewing must be performed by observing the subject's thermal profiles. If near-IR illumination is to be used, then it must be verified that the physiology of the subject is not adversely affected by the light exposure during the dark cycle.

Video Monitoring

Issues associated with dark-cycle monitoring include

1. Bandwidth requirements for the large volumes of video data
2. Physical size of camera, optics, and electronics
3. Engineering trade-offs
4. Image acceptability
5. The subject's biochemical sensitivity to artificial illumination in the dark cycle

These issues are discussed in detail in the following sections.

Bandwidth Requirements

Video data transmission requires large amounts of bandwidth. For example, a black and white video channel compatible with the National Television Standards Committee format, with only 16 levels of gray, requires 37-Mb/sec bandwidth capacity. The bandwidth requirements increase with higher pixel resolutions. These bandwidth requirements are beyond the capability provided by the SSF communications system. Other studies were conducted to evaluate video compression technology and to establish the minimum bandwidth requirements for compressed color video that will be acceptable to users of the facility. The studies indicated that lossy video compression techniques can be used to achieve very high compression ratios. A black and white video channel of 256 kb/sec may satisfy a majority of the dark-cycle monitoring requirements. The use of compressed video facilitates downlinking of several simultaneous channels, and therefore further satisfies the facility's scientific monitoring requirements. The details of the video compression study can be found in reference 3.

Physical Size Limitations

A typical rodent habitat measures approximately 23 in. × 17 in. × 12 in. and can house up to three cages. Each cage requires coverage by two cameras, one for the light cycle and the other for the dark cycle. Six cameras and their associated optics and electronics claim a significant portion of the habitat's volume and power allocation. A practical video system must use a minimal volume. The camera lens must be small, have a large field of view (90 deg), and provide a clear depth of field from 3 in. to 20 in. With an adequate field of view and depth of field, the electronics and mechanisms for pan, tilt, and autofocusing may not be needed, thereby reducing the volume requirement for each camera.

Engineering Trade-offs

This study examined the use of cameras employing three IR technologies: (1) cryogenically cooled, (2) thermoelectrically cooled, and (3) uncooled. These IR cameras were compared to the near-IR CCD camera, which does not require cooling. Figure 2 shows the detectors and operating wavelengths for these four camera technologies. The IR cameras operate in the range of 1 to 200 μm, depending on the technology (ref. 4). The CCD camera operates in the visible range as well as in the near-IR up to 1 μm. Comparisons for image quality were made at wavelengths greater than 0.8 μm, because adverse response of plants and animals to radiation at those wavelengths is negligible.

Table 1 presents some of the trade-offs between these technologies. The cooled IR cameras provide sharper

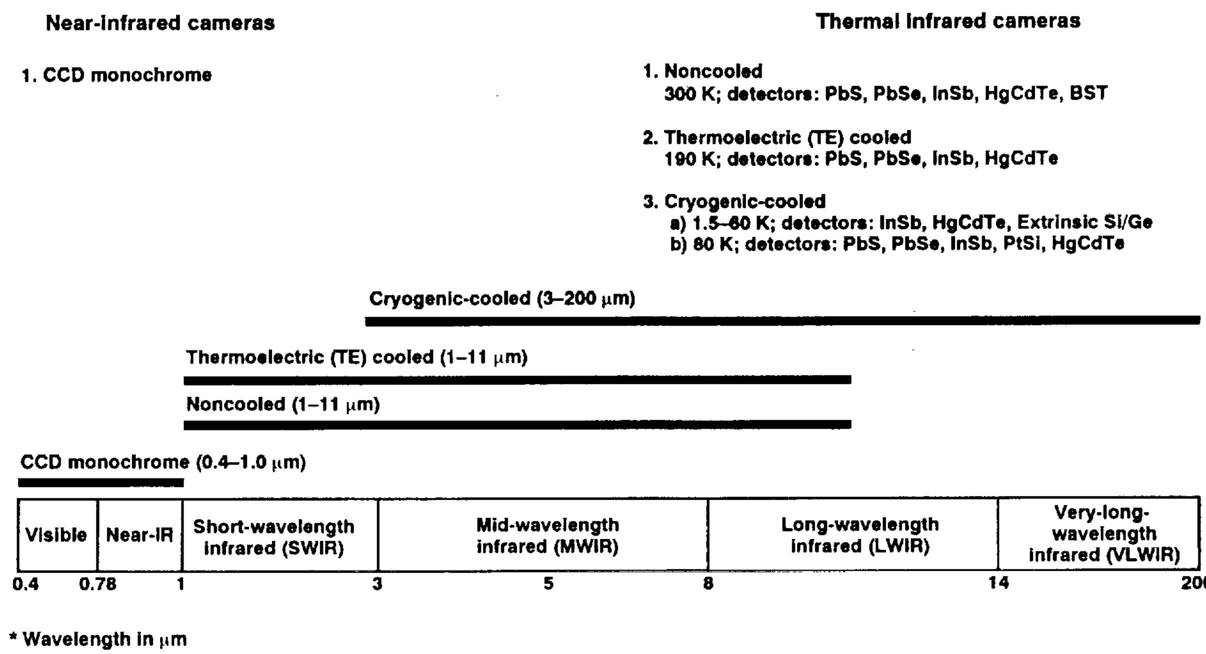

Figure 2. Characteristics of the charged-coupled-device (CCD) and infrared cameras.

Table 1. Engineering trade-offs

Criteria	Trade-offs			
	IR cameras			Near-IR cameras
	Cryo-cooled	TE-cooled	noncooled	CCD monochrome
Weight/volume	15 lb/large	10 lb/med	7 lb/med	3 lb/small
Power (typical)	75 watts	20 watts	4 watts	2.4 watts
Cooling required	Yes	Yes	No	No
Illumination required	No	No	No	Yes
Field of view	<45°	<45°	<45°	Unrestricted
Image quality	Good	Good	Good	Good
Thermal sensitivity	0.01°C	0.01°C	0.01°C	None
Optics	Large	Large	Large/fast	Small
Cost	$75K	TBD	$15K	$2K

images than those from uncooled IR cameras. However, the size and/or power consumption of the cooling unit is prohibitive, and the IR optics are at least an order of magnitude larger than those of CCD cameras. Moreover, the fields of view of IR cameras are smaller, and the optics seemed inadequate for short-distance viewing.

The engineering trade-offs indicate that the characteristics of IR cameras for use in habitats are not favorable. The utility of CCD cameras depends on the acceptability of image quality under appropriate lighting constraints. An experiment designed to evaluate images under various lighting conditions is described in the following section.

Image Acceptability

The use of a near-IR CCD camera is a viable option if two criteria are met:

1. The quality of images is acceptable (equivalent to or better than that obtained using true IR cameras).
2. The lighting frequencies and intensity in the habitats do not affect the subject's physiology in the dark cycle.

In order to compare the quality of images from the IR cameras with those from CCD cameras, videotapes of rats and plants were made using two different cameras: Elmo's CCD monochrome microminiature camera, model type EM-102BW, and Texas Instrument's noncooled Short-Range Thermal Sight IR camera, which operates in the 8–12-μm range. The cameras were inserted in the wall of a habitat-chamber mock-up 19.25 in. long by 9.25 in. wide by 10.75 in. high. The camera lenses were placed 3 in. above the floor to allow optimal viewing of the rat and plant subjects, as shown in figure 3. The habitat mock-up walls were opaque, and no visible light was allowed into the habitat.

CCD camera setup– The CCD camera operates across a large wavelength spectrum peaking at approximately 0.49 μm. The spectral frequencies of interest for this investigation are 0.88 μm and 0.925 μm. A light source that consisted of light-emitting diodes (LEDs) centered at 0.88 and 0.925 μm was used to test the sensitivity of the CCD camera at these wavelengths. The source holds up to 4 LEDs and was attached inside the habitat 2 in. directly above the camera lens, pointing into the habitat volume.

The CCD cameras were used to take three 30-sec video segments of the activities of a laboratory rat in a habitat illuminated by 0.88 μm LEDs set at various light intensities, as shown in table 2. For each recording, the

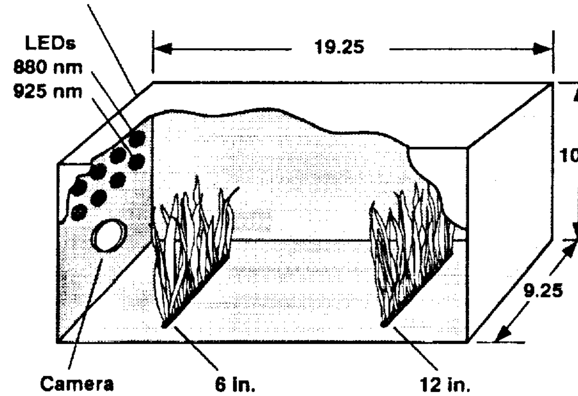

Figure 3. Habitat mock-up.

Table 2. Light intensities for various LED configurations

Wavelength	880 nm			925 nm		
Number of LEDs	1	2	4	1	2	4
Light intensity at 6 in.	24	50	95	7	14	28
Light intensity at 12 in.	6	13	25	1.7	3.5	7

Note: Light intensities are in $\mu W/cm^2$

light intensity was changed by adjusting the power supplied to the LEDs or by changing the distance of the subject (plants) from the light source. Two standard distances of 6 in. and 12 in. from the LED source were used for plant experiments. Table 2 also shows the video segments recorded and the associated light intensity for plant and animal (rat) subjects. Note that the rat was free to move about in the habitat volume.

IR camera setup– A similar experimental setup was used to record video segments of the same subjects using the Texas Instruments IR camera. In these tests, the LED light source was removed and no other light source was used, because IR sensors respond to heat.

Quality of images– The quality of the CCD-camera images improved as the light intensity of the LEDs increased. Acceptable image quality was achieved with light intensities of 10 $\mu w/cm^2$ and greater. With CCD technology, the quality of images increased as a function of illumination, whereas IR technology had no controlling factors for improving image quality. Figure 4

Figure 4. Images of rat subjects obtained by CCD (left) and IR (right) cameras.

shows a comparison of rat images from the IR and CCD cameras. Figure 5 shows a similar comparison for plant images. This figure illustrates the particularly poor quality of IR images for plants—the leaves are not distinguishable from each other. The comparison clearly demonstrates the superior image quality that can be achieved using the near-IR CCD camera.

Effects of Near-IR Illumination on Rodent Biochemistry

The engineering trade-offs and the quality of images achieved clearly demonstrates that the near-IR CCD camera is preferable for dark-cycle monitoring. However, since this camera depends on the use of an illumination source, it was necessary to verify that the illumination would not affect the circadian rhythm of the rats. Therefore, an experiment was designed by George Brainard of Jefferson Medical College to quantify the effects of near-IR photic stimuli on rat circadian rhythms. The indicator used for this investigation was the melatonin level in the pineal gland. The melatonin level drops to almost zero when rats are adversely affected by light exposure.

Four groups of eight Sprague Dawley rats were housed in a completely dark room. One group of rats was exposed to 10 $\mu w/cm^2$ light at 0.88 μm; the second group was exposed to 33.8 $\mu w/cm^2$ at 0.88 μm, and the remaining two groups served as the control and were kept in complete darkness, with no artificial light. Immediately after the exposure, the rats were sacrificed and their pineal glands were removed. Figure 6 shows the melatonin level for each group of rats. The melatonin level remained high in all cases, indicating that the circadian phase was not affected.

The experiment proved that a 0.88 μm light source emitting up to 33.8 $\mu w/cm^2$ could be used without significantly affecting the biochemistry of the rats in the dark cycle. This result, however, examined only one possible effect of illumination on rats. There may be other sensory perceptors of photic inputs that are independent of melatonin indicators. In order to extrapolate our findings to other organisms and other physiological effects, more studies must be performed.

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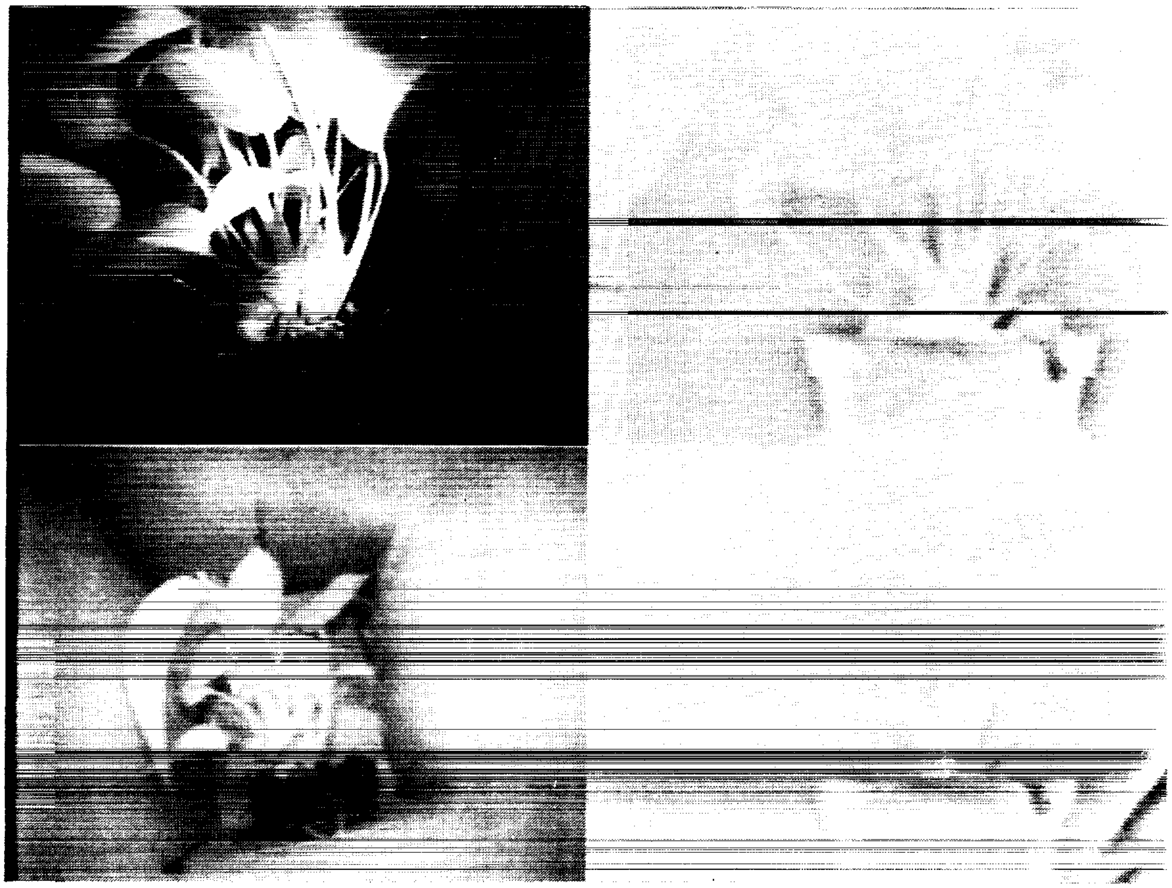
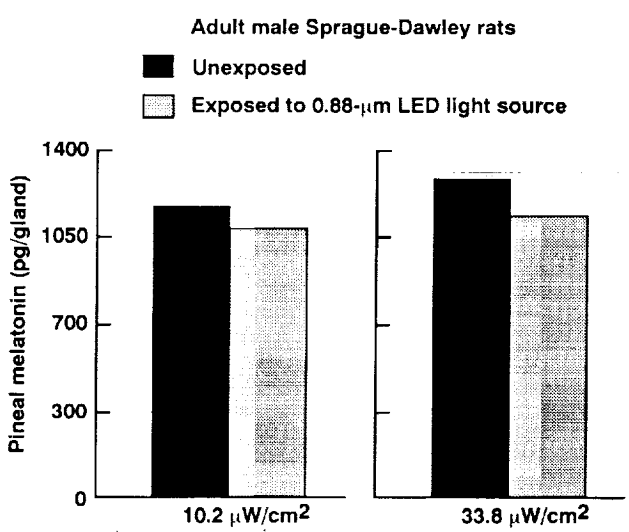


Figure 5. Images of plant subjects obtained by CCD (left) and IR (right) cameras. The image on the upper left was taken at a distance of 6 in., the one on the lower left at 12 in.



Courtesy of Dr. George Brainard, Jefferson Medical College

Figure 6. Melatonin level in the pineal glands of rats after selected light exposures.

Conclusions

Dark-cycle monitoring provides several challenges for video monitoring on board SSF. Trade-offs such as weight, volume, and power of the video equipment; engineering and technological capabilities; image acceptability; and the biochemical effects of artificial light on life sciences subjects must be considered in order to realize an optimal video monitoring capability. This study examined these four areas, and it validates the use of CCD technology for dark-cycle monitoring on SSF. The availability of a thumb-size CCD camera that is sensitive at the required wavelengths will use substantially less of the habitat volume. The engineering parameters and excellent image quality obtained by the CCD camera make this technology preferable to the conventional IR cameras. Finally, the light intensity needed to provide excellent CCD imagery at 0.88 μm has no known effect on the animal and plant physiology as measured by the melatonin indicators. With the caveat that it is likely but not certain that there is no physiological impact, the 0.88-μm threshold and CCD imagery are recommended for safe use for monitoring the animal and plant habitats during the dark cycle.

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