NASA's Myriad Uses of Digital Video

By Rodney Grubbs, Walt Lindblom, and Sandy George

Since its inception, NASA has created many of the most memorable images of the past century. From the fuzzy video of Neil Armstrong taking that first step on the moon to images of the Mars surface available to all on the internet, it has provided visuals to inspire a generation, all because a scientist or researcher had a requirement to see something unusual. Digital television technology will give NASA unprecedented new tools for acquiring, analyzing, and distributing video. This paper will explore its DTV future. The agency requires the realtime transfer of video between NASA centers. Specifics will be provided relating to the video infrastructure, including video from the space shuttle and various centers. The pros and cons of interlace and progressive scanned images will be presented and compared. Film is a major component of NASA's image acquisition for analysis usage. The future of film within the context of DTV will be explored.

If one was asked to name some of the most memorable moments of the U.S. space program, the images that instantly come might include the shadowy view of Neil Armstrong taking his first step on the moon, the instrumentation ring of the Saturn V rocket separating, with Earth in the background, John Young taking the Lunar Rover out for a spin on the moon, the first images of Earth from the moon during Apollo 8, the launch of the lunar module from the moon, the first untethered space walk from the space shuttle, three space-suited astronauts grabbing a satellite with their hands in the cargo bay of the space shuttle. The list might go on and on.

While NASA's critics might complain that the agency spends too much time and money doing public relations, the reality is most, if not all, of these images were obtained using systems designed to aid scientists, researchers, and engineers. The need to see what cannot be seen by human eyes drives NASA to build and deploy camera systems in some of the most unlikely places. Everytime the space shuttle is launched, more than 100 film and video cameras record the event. Some of the cameras are used by engineers to monitor a component's performance during launch. Others look for propellant leaks and monitor safety-related requirements.

Currently, there are two ways for the public to receive video and film imagery: via NASA TV, the primary way the media receives video or a requesting through the Freedom of Information Act. When there isn't a manned space mission underway, NASA uses one of its two commercial satellite transponders to provide content for media stories, called video files, that include sound bites and b-roll explaining a particular discovery or technology. The agency also provides live interviews with researchers and scientists directly to individual television stations. During manned space missions, live video from space, coverage from mission control, and media opportunities and press briefings are uplinked.

In all cases, the video is provided "raw," to allow broadcasters and nonbroadcasters the opportunity to edit the footage and provide their own supers and logo insertions. Requesting film, video, or photographs through the Freedom of Information Act is a much more laborious process, requiring reimbursement to the government for any reproduction and shipping costs.

NASA is now working to transition its infrastructure for the digital world. The Space Act that created the agency in 1958 calls for dissemination of information about its activities in the most practical method possible, and for years, television has been the best way to fulfill this charge. In the future, NASA hopes to take advantage of digital technologies to continue providing memorable recordings of discoveries and endeavors in space. More importantly, though, this new technology will enhance the ability of scientists, researchers, and engineers to conduct their research and monitor experiments.

NASA and DTV Technologies

There are several areas where digital television technologies enhance NASA's missions. Like other entities that distribute video, the agency has a limited bandwidth capacity through which to transport video, audio, and data. Downlinks from the space shuttle are currently limited to 50 Mbits/sec, with a payload capacity of around 43 Mbits/sec. Transmission capabilities include satellite links; ATM; and in some cases, Next Generation Internet. Therefore, high-quality compression of video is crucial to the continued success of highly advanced research.

High-quality image capture is also a requirement. Getting into orbit is very expensive, so having high-quality video transmitted to the ground can save money and lives should something go wrong with an experiment or a space vehicle. There have been occasions where video was the only way to determine whether an experiment in the shuttle succeeded or failed. Every launch is monitored in realtime and analyzed afterward by utilizing video and film from high-speed cameras. Debris, leaks, and anomalies within the propulsion systems are examples of what is examined after every launch. Before an advancement to the shuttle is flown, hours of ground testing is completed. Video and high-speed film (usually transferred to video) are used to analyze the performance of engine components or space flight hardware. When film isn't practical or possible, it becomes very

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important that the video imagery obtained is capable of extracting detailed, consistent information. Digital video technology provides excellent capabilities for providing high-quality motion imagery that is useful to scientists, researchers, and engineers, while also fulfilling the mission to disseminate that video to the public.

Since much of what researchers are seeking is not only finite and detailed, but also something that occurs in less than a second, high frame rates are often required. For that reason, high-speed film will continue to be the image capture format of choice for such things as launch analysis. The advent of advanced telecines, with the ability to capture film frames as data, dramatically increases the value of film as an analysis tool.

Each of these nonbroadcast uses of video will be explored in more detail.

Distribution

NASA's existing television broadcast system utilizes satellite and terrestrial links. Two satellite transponders on GE Spacenet 2 are used for broadcasting video and data. Transponder 5 is used primarily for internal distribution of video and data between centers.

Transponder 9 is used to send video to media outlets and other centers, and terrestrial links are also used to facilitate video transfer between centers. The terrestrial links are via a wide area network (WAN) referred to as the NASA integrated service network (NISN). The NISN currently uses a Sprint ATM backbone infrastructure. The sites have OC3 or DS3 connectivity.

During a space mission, the current on-orbit configuration utilizes both transponders. The shuttle sends its signal to the Tracking and Data Relay Satellite System (TDRSS). The downlinked signals from the shuttle are received at the NASA ground terminal (NGT), located at White Sands, NM. NGT receives the signal and retransmits it via satellite transponder 5. Signals from transponder 5 are then downlinked at the Johnson Space Center (JSC) and the Marshall Space Flight Center (MSFC). At JSC, the signal is demultiplexed into individual data and video streams and sent to other NASA centers or scientific research contacts as requested. JSC and MSFC transmit the video via transponder 9 for reception by the news media (Fig. 1).

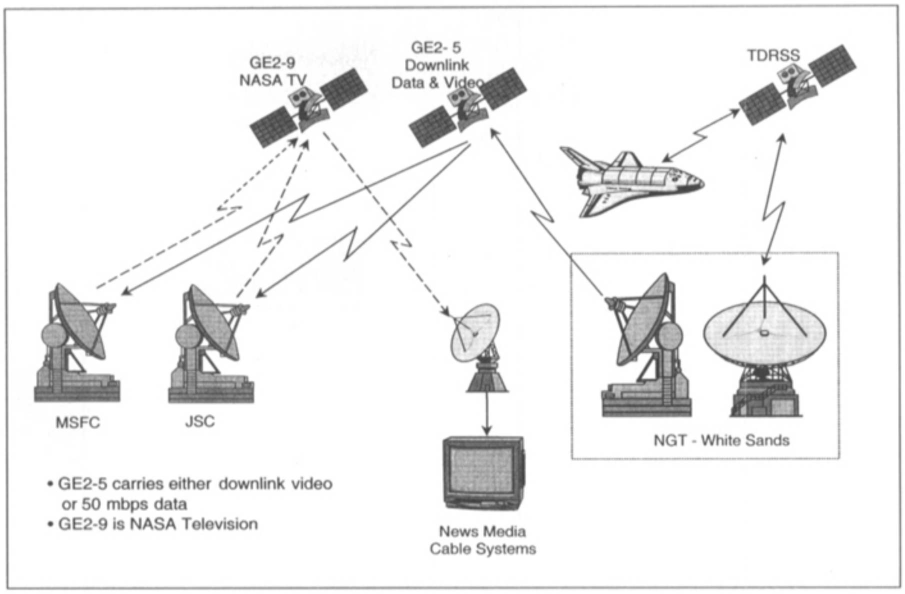


Figure 1. Current on-orbit television distribution configuration.

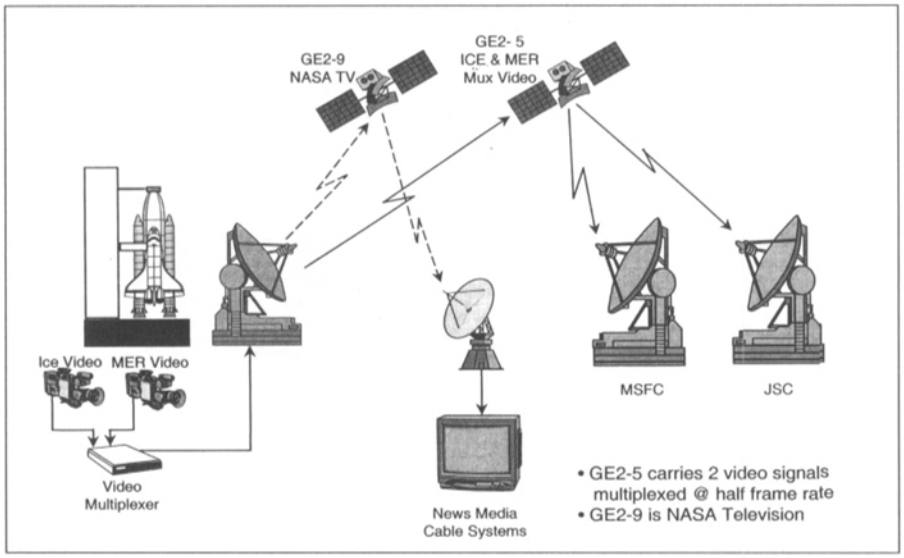


Figure 2. Shuttle launch video configuration.

During a shuttle launch, two video signals are multiplexed at half frame rate. The signals are used by propulsion engineers at MSFC to search for engine anomalies and by shuttle engineers at JSC for readiness evaluation. The signals are referred to as ICE and MER video and are carried by transponder 5. Public dissemination of NASA video by the media satisfies the agency's objective to inform the public of its projects and goals. The news media signal is carried over transponder 9 (Fig. 2).

The use of quality compression techniques is crucial, especially in space, where limited bandwidth downlink capabilities exist. Video signals must share limited bandwidth with experiment and telemetry data. During video compression, it is important not to experience data loss. This data is valuable and required for use by the NASA scientists. The agency's DTV working group has conducted MPEG-2 compression testing with its researchers and developers. The test scenario examined six different data rates, which ranged from 2 to 12 Mbits/sec, and at three different groups of pictures (GOPs), which ranged from 1 (all I frames) to 16.

The MPEG test was configured

using Betacam SP videotape format VTRs for playback and recording. The playback signal was routed as NTSC composite video into an MPEG-2 codec. The coding structures were adjusted and optimized to enhance temporal resolution and spatial resolution, and locate a median point between temporal and spatial resolution. The encoded/decoded video was output as NTSC composite video and recorded.

The audio signal was also routed through the codec and encoded at 128 Kbytes/sec, Musicam format. The majority of the scientists were satisfied with 8 Mbits/sec or higher at GOP of either 8 or 16. Figure 3 shows how the test scenario was configured. This testing laid groundwork for evaluating future acceptable compression levels to support the scientific community.

NASA continues to examine industry initiatives to improve video compression algorithms in order to improve throughput and performance. Enhancements in this area will be key factors in reducing the cost of transmitting video while maintaining or improving levels of service.

The agency will still utilize satellite transmission to support needed video multicast transmission requirements until terrestrial service offerings are available that provide needed capabilities at a lower cost with comparable or greater reliability. Figure 4 depicts the possible on-orbit configuration in the near future.

NASA's future, long-term goal for distributing video is to eliminate "tape" copies by sending electronic files. In this mode, the video files would be placed on a video server and customers would access the files via direct server connectivity or an URL connection.

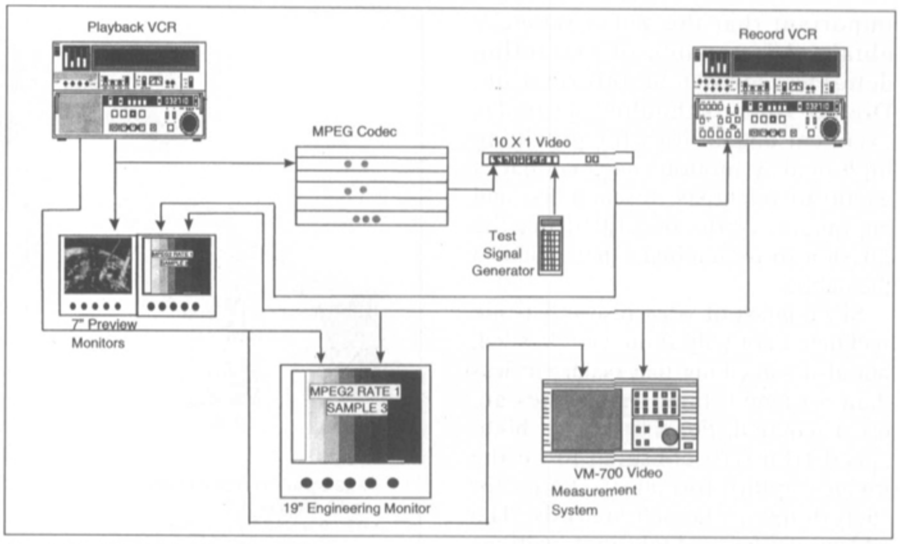


Figure 3. MPEG test configuration.

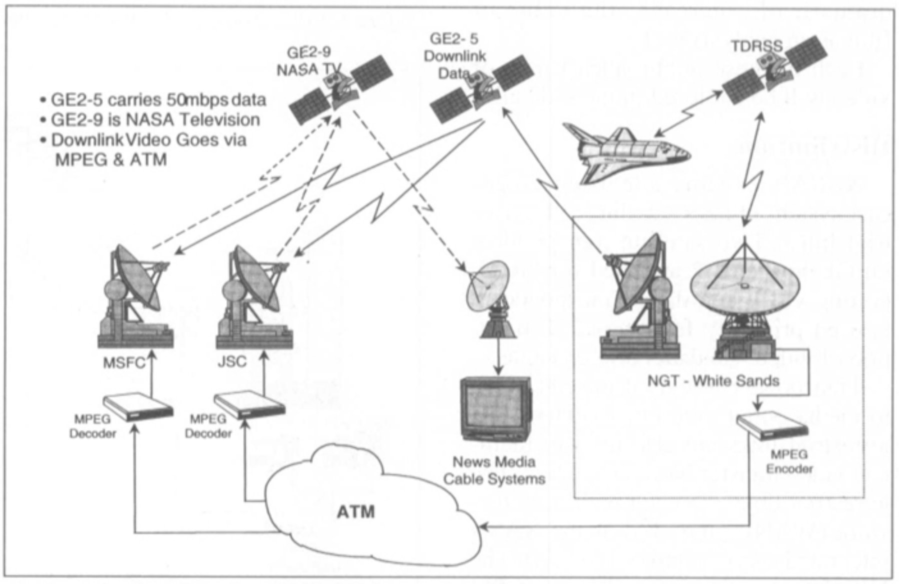


Figure 4. Analog/digital hybrid distribution.

Digital Video Imagery

In the analog television environment, video has played an important role in verification of events; but, due to the limitations of analog, video has not typically been used as a measurement tool. With square pixels and the ability to transfer images directly into computers, digital television is providing new tools for researchers.

As in many organizations, the migration to digital video within the agency has been slow. Each field center has an independent budget for video systems upgrades. A few centers have digital video capability, but the majority still face the transition to digital. Because of this, NASA has a unique opportunity to implement digital video systems that best fit requirements for analysis, operations, and public release. In many cases, this will be a mix of standard-definition television (SDTV) and high-definition television (HDTV). Not all requirements need HDTV: monitoring ice build-up on a fuel line prior to a shuttle launch, for example, does not need a great deal of detail. Monitoring the start of the space shuttle engines is much more critical. Often problems that occur during engine startup are detected by instruments and leave no trace except for telemetry data and the images captured by film or video. This imagery is of vital importance in the diagnosis of problems.

One area of consensus within the video community is that there is little room for multiple video standards when video is to be interchanged between centers. To determine the standards to be used, an agency-wide standards group, part of the DTV Working Group, was formed. It has the responsibility to recommend acquisition, recording, and distribution standards to be adopted by NASA. Since it will not be practical to implement multiple SDTV or HDTV standards, it is vital that this group choose

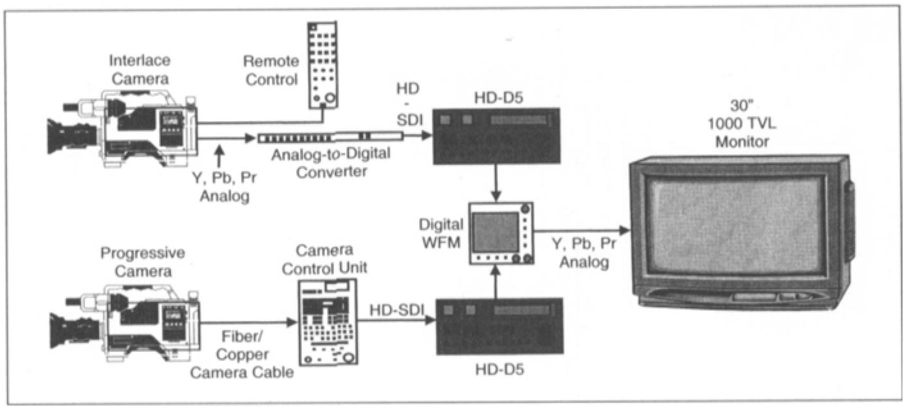


Figure 5. Interlace/progressive test configuration.

standards that provide the best overall video product for all requirements.

There are some significant implementations of SMPTE 259-based systems in place or being implemented in 2000. Because of this, and the lack of full systems in 480p, the standards group is recommending all new SDTV implementation be compatible with SMPTE 259. This will be evaluated periodically by the standards group.

For HDTV, the choice was not as clear-cut. The decision of the major broadcast networks to choose different HDTV formats caused many in the standards group to question which format would be best for NASA. All HDTV formats are considered to have acceptable resolution requirements. Spatial resolution is important, but temporal resolution is more critical for research/analysis video. To help determine what choice to make, a comparison test for temporal resolution between interlace and progressive scan HDTV was conducted.

The test configuration used a prototype 720p portable camera equipped with an 18 x 7.8 HD lens, and fiber-optic connection to a CCU. A SMPTE-292 HD SDI output from the CCU was fed to a D5-HD VTR. Output of the VTR was fed to the A input of a digital waveform monitor.

The analog outputs of an HDCAM camcorder, equipped with a 15 x 8 HD lens, were fed via a coax bundle to an analog-to-digital (A/D) converter. A handheld controller was used to control camera functions. The SMPTE-292 output of the A/D converter was fed to a D5-HD VTR and the output was fed to the B input of the digital waveform monitor. Sony confirmed that live camera feed from the analog outputs of the HDCAM is not filtered to 1440 pixels.

A digital waveform monitor was used for setup as well as a digital-to-analog (D/A) converter. The analog outputs of the waveform monitor were fed to a 30-in. HD monitor with 1000 TV lines of resolution (Fig. 5).

Cameras were set up by one engineer to be as closely matched as possible using the waveform monitor and the picture monitor. Parameters checked were black and white levels, gamma and knee settings, and detail level. Black and white levels were matched for each test object; the other set-up items were left at factory settings. Gamma, knee, and detail settings were matched on the resolution chart at the beginning of the test and not adjusted again.

Test material included:

- NTSC 4 x 3 resolution chart.
- Vertical and horizontal lines charts.
- Line chart—12 lines/in. on 8½ x 11 paper.
- Back focus wedge chart.
- Text chart with various sizes of type.
- $20 bill.
- Soccer ball.

The line chart, back-focus chart, and text chart were rotated on a turntable to simulate motion. The angular rate of motion was 3.34°/field/frame at 59.94 frames/sec. All other material was shot static with the exception of the soccer ball, which was bounced off the floor.

It was theorized before the test that distortions would be added to an interlaced picture by doing still images in field mode. Stills in this mode use a single field repeated to make a complete frame. This in effect does line doubling of the signal, which causes horizontal lines to be thicker than they should be. In practice, this was found to be the case. When using frame still mode on the VTR, interfield jitter precludes the use of the image for analysis (Fig. 6). Video for analysis is used more as a series of stills than as motion video, which makes freeze frame performance critical.

Progressive scan video does not have this problem. There was never a case where jitter or line doubling occurred. It should be noted that with either interlace or progressive, it is necessary to shutter the camera to achieve acceptable results with moving objects. Even at 1/1000 of a sec shutter speed, the outside edges of rotating charts were slightly blurry or

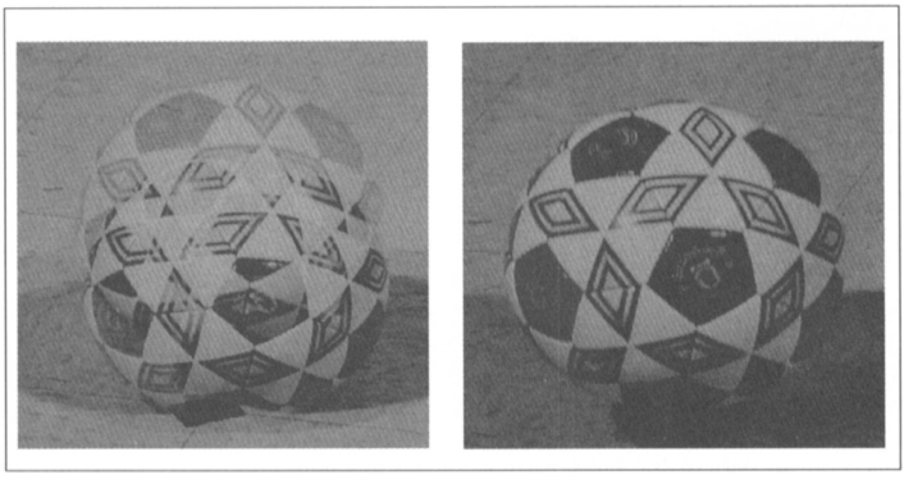


Figure 6. Freeze frame: (a) interlace HDTV; (b) progressive HDTV.

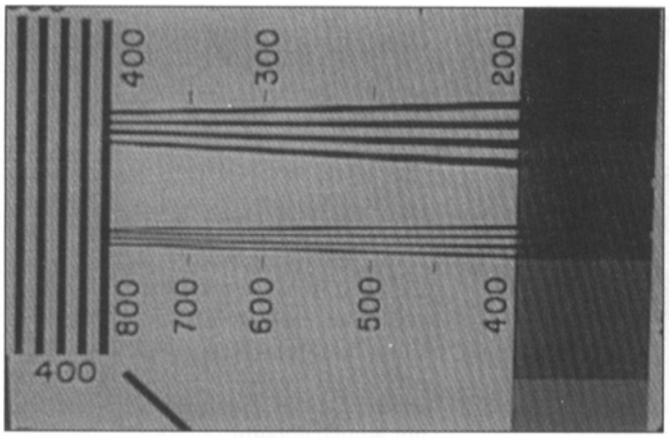


Figure 7. Interlace HDTV: resolution chart horizontal wedges.

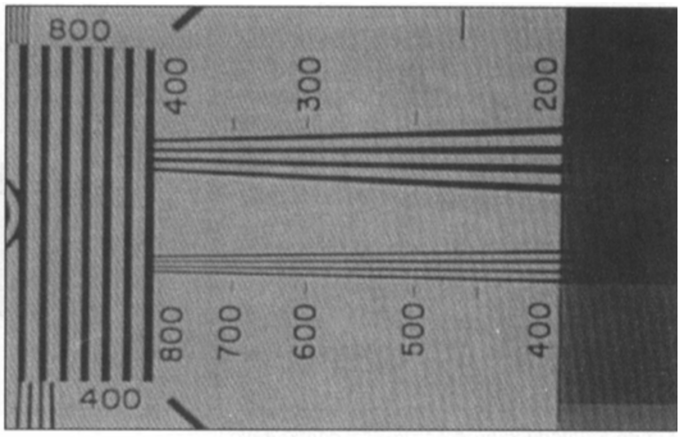


Figure 8. Progressive HDTV: resolution chart horizontal wedges.

Figure 9. Interlace HDTV: frame freeze, close-up of $20 bill engraving.

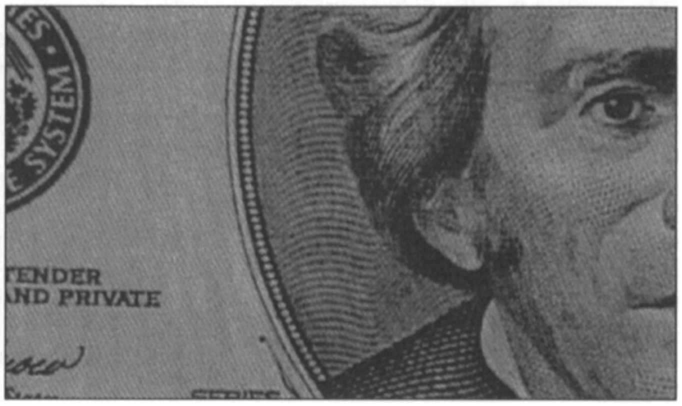


Figure 10. Interlace HDTV: field freeze, close-up of $20 bill engraving.

Figure 11. Progressive HDTV: frame freeze, close-up of $20 bill engraving.

showed some aliasing.

Of greatest interest was the performance of the cameras on high-detail still images. It was theorized before the test that there would be little significant difference between the cameras, with the edge going to the interlace camera due to its higher resolution imagers. This did not turn out to be the case.

On the resolution chart, both cameras showed 800 lines of resolution (the limit of the chart) in both horizontal and vertical resolution, although only horizontal resolution was valid due to framing of the chart. In frame or field freeze mode, the interlace camera (Fig. 7) had significant twitter on the horizontal wedges at 600 lines and above. The progressive camera (Fig. 8) showed no distortions in freeze frame.

With the $20 bill shot edge to edge, the engraving pattern behind the portrait of Andrew Jackson showed significant distortion on the interlace camera regardless of mode. In frame freeze (Fig. 9), beat patterns formed chevrons in part of the pattern (this was partially due to the monitor). In field freeze (Fig. 10), the curves in the lines of the pattern changed direction, from a downward curve to an upward curve. The progressive camera (Fig. 11) showed light beating in the pattern, resulting in a slight moiré effect (also partly due to the monitor). Aside from that, there were no distortions to the image.

It was concluded from the tests that interlace video is not usable for analysis work of any video with motion. There are accuracy problems in the picture that prohibit the use of interlace video even when shooting still images of very fine detail. Progressive scan video does not suffer from the same problems and provides pictures with a high degree of accuracy when compared to the original source.

Based on these tests, NASA is planning to implement progressive HDTV for all video to be used for analysis purposes. Use of interlace HDTV for other applications will be an interim solution until progressive equipment is readily available.

Film and HDTV

Everytime the space shuttle lifts off there are at least 60 high-speed 16mm and 35mm cameras rolling. Some are documenting specific areas of a space shuttle main engine, some look at the bottom of a solid rocket booster, and others track the entire vehicle throughout liftoff. Occasionally, there are high-speed film cameras located in the nose cone of the solid rocket booster to document parachute deployment during the descent of the booster back to the Atlantic Ocean. In all cases negative film is the medium of choice due to its high resolution and ability to record events with a high frame rate. The average camera recording a launch films at 100 frames/sec.

After a launch, a team of film analysts views each roll for any anomaly. Sometimes a video camera records something unusual, so the high-speed film from a camera with a similar view is used to help determine what the anomaly might be. Normally a special film projector is utilized that allows a specific frame from a film print to be observed on a screen without damaging the film. If further analysis is required, a film transfer to analog component video is provided, then selected frames are digitized using a mid-range computer.

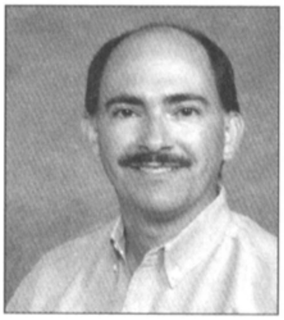
In the future, specific frames of video will be converted directly as data for analysis. Tests have been conducted utilizing an HD telecine and color corrector. Frames from an A-wind first generation film print were color corrected and saved as 2K-by-2K data files on a digital linear tape. Also, portions of selected frames were saved as 2K-by-2K files. Not surprisingly, the images from 16mm frames were very grainy, particularly when a portion of the frame was digitized. Nevertheless, the image was sufficient to determine what occurred during that fraction of a second in time, in this case, the drogue shoot door hitting the end of a main engine during the launch of STS-95, John Glenn's return to space. In all cases, the image quality from 16mm and 35mm film frames using an HD telecine was far superior to any frame capture methods utilized currently.

In addition to launches, NASA conducts research and testing at its field centers that require high-speed motion picture film. In some cases, such as explosive bolt testing, the event being recorded occurs in thousandths of a second. HD transfers at 30 frames/sec eliminate 3:2 pull-down, allowing for frame-by-frame continuity. Conversion of frames or portions of frames directly to data, will greatly enhance the value of film as a recording medium for research and engineering.

Conclusion

In the coming decade, NASA has plans to put a remote-piloted aircraft on Mars; capture and return comet dust; and explore ice caps on Europa, a moon of Jupiter. With DTV technology, images from missions such as these will take their place beside memorable ones from the past. At the same time, DTV technology will give researchers better tools to inspire a new generation of exploration.

THE AUTHORS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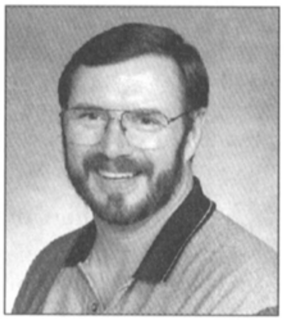
Walt Lindblom


Sandy George

Rodney Grubbs began his career as a co-op motion picture photographer at NASA's Marshall Space Flight Center while a student at the University of Alabama. After graduating in 1988 with a degree in film and broadcast production, he began working for NASA full-time. Since then he has worked as a motion picture photographer, film editor, director, colorist, and producer. Since 1997, he has been the lead for NASA's DTV Implementation efforts, and heads the NASA DTV Working Group.

Walt Lindblom, a 26-year video professional, started his career in 1974 as master control operator and tape editor with educational television in Birmingham, AL. He has held engineering and operations positions in commercial and industrial television.

Since 1985, Lindblom has worked as a NASA contractor designing, implementing, and managing various video systems. During that period, he helped develop the NASA compressed video teleconferencing system and managed Marshall Space Flight Center's television operation. Currently, he is part of the team chartered with planning and implementing NASA's digital television transition.

Sandy George obtained a B.S. in electrical and computer engineering at the University of Alabama in 1986. Since 1987, she has been involved in the design and implementation of data, voice, and video systems supporting a wide variety of NASA mission objectives. She managed projects for implementing telecommunications services to NASA's international partners, including directing the installation of a large network infrastructure in Moscow. She has also worked on designing and enhancing voice and video teleconferencing systems supporting NASA agency requirements.

George has been with Computer Sciences Corp. since 1994 and currently evaluates digital television implementation solutions at the NASA DTV Project Office.