A DUAL COMPRESSION ETHERNET CAMERA SOLUTION FOR AIRBORNE APPLICATIONS

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ABSTRACT

Camera technology is now ubiquitous with smartphones, laptops, automotive and industrial applications frequently utilizing high resolution imagine sensors. Increasingly there is a demand for high-definition cameras in the aerospace market – however, such cameras must have several considerations that do not apply to average consumer use including high reliability and being ruggedized for harsh environments.

A significant issue is managing the large volumes of data that one or more HD cameras produce. One method of addressing this issue is to use compression algorithms that reduce video bandwidth. This can be achieved with dedicated compression units or modules within data acquisition systems. For flight test applications it is important that data from cameras is available for telemetry and coherently synchronized while also being available for storage. Ideally the data in the telemetry steam should be highly compressed to preserve downlink bandwidth while the recorded data is lightly compressed to provide maximum quality for onboard/ post flight analysis.

This paper discusses the requirements for airborne applications and presents an innovative solution using Ethernet cameras with integrated compression that outputs two steams of data. This removes the need for dedicated video and compression units while offering all the features of such including switching camera sources and optimized video streams.

Key words: Ethernet, video, camera, compression, flight test

INTRODUCTION

Digital cameras have become ubiquitous in recent years as their prices have dropped. Today, almost every smartphone and laptop, as well as an increasing amount of cars and even children's toys, have a camera sensor. Vendors like GoPro have also developed more rugged cameras intended for outdoor activities while providing high-definition images. High-definition cameras for flight test have yet to become so widespread despite the desirability of having several cameras monitoring surfaces, carriage and internal systems. One of the key reasons for this is that while commercially available camera technology can be used in some limited capacity, they are not specifically designed for flight test applications.

Broadly speaking, the requirements for flight test cameras can be split into two categories – camera characteristics and system level design and integration.

CAMERA CHARACTERISTICS

Camera characteristics describe the physical elements a flight testing camera should have in order to meet both image and environmental requirements. Just as other sensors, data acquisition units or recording equipment are built according to specific flight testing requirements, cameras should also be designed with the application in mind. The most important of these considerations include the following aspects.

Signal quality requirements

Signal quality starts at image capture. Not all digital sensors / processing hardware can meet required image capture. For example, for flight tests it's important to have a 'global shutter' to eliminate the smearing effect caused by a 'rolling shutter' in Figure 1. Rolling shutters are common in consumer cameras and capture an image frame by scanning rapidly vertically or horizontally. Since there is a time difference between different parts of the frame, moving elements, such as spinning rotor blades, can appear distorted. Global shutters capture the entire frame in once instance of time and thus don't suffer this smearing effect.

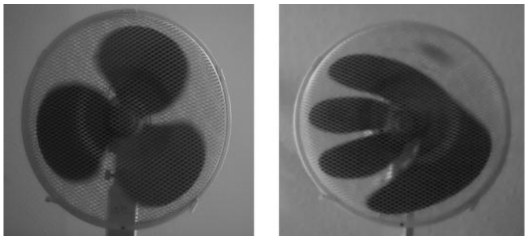

Figure 1: Global shutter (clear) and rolling shutter (distorted)

The resolution of the CCD sensor and the color processing of a camera, are also important aspects for a proper image quality.

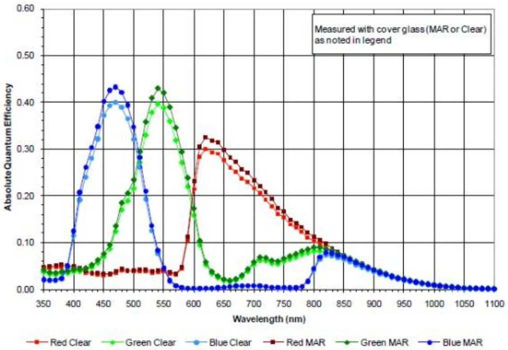

Figure 2: Spectral sensitivity of a typical CCD

HD-resolution (High-definition) helps to increase the viewing angle without losing image quality. The human eye has a field of view of approx. 50° at an angular resolution of ~1'.

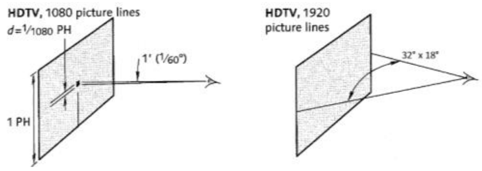

Figure 3: Viewing angles at HD resolution

A standard full HD sensor with a resolution of 1920x1080 pixels at an angular resolution of 1' results in a horizontal viewing angle of 32°; while an SD-sensor (Standard Definition) with 720x576 pixels results in a viewing angle of only 12°.

Other important aspects during image capture include low noise readout, black level control, adjustable exposure time, gain, color settings amongst others. Therefore the following image-processing functions are essential for appropriate image quality during test flights:

- Defect pixel correction
- Automatic exposure control
- Automatic gain control
- Automatic white balance control
- Lens distortion correction

Meeting external environmental conditions

Factors such as vibration, shock, humidity and temperature could damage or reduce the effectiveness of the units. Flight test applications are particularly subject to harsh environments as the aircraft must execute maneuvers that may not be encountered in typical operational applications. Without testing the aircraft and its systems to the limit, it is difficult to prove the validity of the design assumptions and to ensure the safe operational limits of the aircraft are recorded.

Therefore cameras have to be designed to meet the strong environmental requirements. For example, a camera may need to operate on a runway at 50ºC and shortly afterwards at -30ºC – such thermal differences can result in changed impedances of components due directly to temperature or indirectly though effects such as condensation. Such can alter the quality or reliability of the unit. Similarly, high levels of vibration or shock subject the electronics to stresses which could damage circuit boards, components or the connections between (solder, connector points). Commercially designed electronics which are not expected to encounter such extremes are unlikely to invest the extra resources to protect the electronics from such effects as these increase the manufacturing/ quality control costs.

Table 1: External Environmental Requirements

Temperature range	-55°C to +85°C
Altitude	50.000 ft (116 mbar)
Humidity	Cycles between 95% / 65°C and 85% / 38°C (for 16 hours)
EMI (emissions)	10 kHz to 6 GHz
EMI (susceptibility)	100 MHz to 6 GHz
Lightning, indirect effect	up to 1600 V / 107 A
Shock	40 g / 10 ms
Vibration	6 grms, 5-2000 Hz

Rugged optical entrance windows are required to protect against scratches and breakage – sapphire glass has these properties. A method to prevent icing and misting on the lens, such as a heating element is also recommended.

For safe handling of a camera in the flight test environment, ruggedized connectors help to maximize the availability of the camera.

To ensure that these requirements are met, the camera has to be qualified (DO-160, MIL-STD461, MIL-STD 464, MIL-STD 810, MIL-STD 704) at certified laboratories.

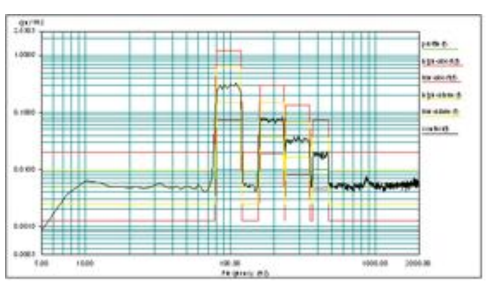

Figure 4: Random Vibration Test

But also at quality management (ISO 9100, EN/AS 9100) and Manufacturing (IPC-A-610 E, IPC-A-600, IPC J-STD-011, IPC/WHMAA-A-620) a lot of standards have to be taken into account.

Matching to flight test mission

Each flight test mission has its own needs. For example a wide range of lenses are needed to get the important information at maximum resolution. Viewing angles from 10° for small objects far away, up to 95° to get a wide scene overview are useful. An appropriate lens should have adjustable focus plane and aperture.

Also an easy mounting mechanical interface is important. The camera should be easily mounted in a secure manner with the ability to fine tune the direction of observation.

Figure 5: Mounting Kit

All adjustable camera features have to be configurable in a way that doesn't require further actions during a test flight.

SYSTEM LEVEL CHARACTERISTICS

At a system level, data from the camera is typically sent to ground via a telemetry bridge and to a recording device. This is relatively straight forward for a single high-definition or a few standard definition cameras. The onboard data acquisition system is likely able to support such via video compression cards. However, once several high-definition cameras are required the bandwidth required for uncompressed video can overload the data acquisition system e.g. full HD video at 60 fps can take up to 3 Gbps of bandwidth per channel as shown in

.

Table 2: Bandwidth requirements for uncompressed video

Format	Pixels [M]	Frame rate [fps]	Color depth [bit]	Bandwidth [Gbps]
SD 576	.414	24	24	0.24
HD 720p	.922	30	24	0.66
HD 1080p	2.07	30	24	1.5
HD 1080p	2.07	60	24	3

One method of solving this problem is to use dedicated video multiplexors and management units to isolate the camera network from the FTI system. One can then use a dedicated video recorder to store uncompressed video data and selectively send channels of interest to ground via a telemetry bridge. Figure 6 shows an example of such a system. However, often these video management units limit the data from cameras as the telemetry system and the recorder required to handle such raw data rates can be expensive, large and heavy. A work around is to lower the frame rate, e.g. send only every tenth frame, or the color depth e.g. a monochrome image might yield the data required.

In addition, setting up and managing the video management unit can be difficult as they can be complex when trying to direct limited data to different locations. Another issue is that the video is not synchronized with other FTI parameters resulting in time consuming post processing work if correlation between the video and other data is required. The use of separate boxes also adds weight and reduces available space.

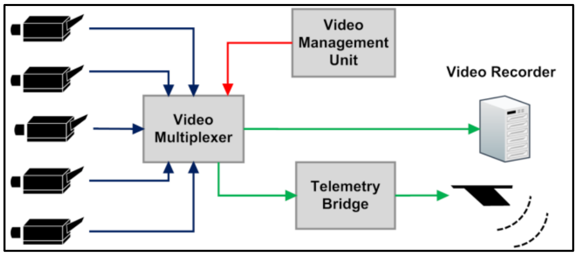

Figure 6: Camera system using video multiplexors and management unit

A method to overcome some of these problems is to use video compression. As raw HD video can be over 1 Gbps, more bandwidth can be taken by one video channel than the entire data acquisition of a very large network. Compressing this data using an industry standard algorithm can reduce the bandwidth to a more reasonable amount without significantly affecting the image quality.

Compression standards

Often video data contains a lot of redundancy such as intra and inter frame redundancy. Intra frame redundancy is where one part of frame is similar to another or inter frame redundancy where successive frames are similar to each other. Figure 7 shows an example of an aircraft wing where there are areas which are very similar to each other, such as sections of sky and the wing (intra frame redundancy), and sections which will change little between frames, such as the wings (inter frame redundancy).

Figure 7: Video data can contain significant redundancy

Figure 8 shows how an inter frame scheme can be setup. The I frames are complete picture where the P frames only contain information about the difference between the previous frame to the next. The more P frames there are in comparison to I frames, the less information in needed to reconstruct a video. An advantage of only using more I frames and less P frames (or none at all) is it is a more robust scheme against corruption due to signal drop outs. If an intra coded frame is lost, say due to a transmission error, then the following predicted frames will also be corrupted. In practice these effects can be minimized with modern hardware and by selecting appropriate trade-offs between high compression and robustness against signal drop-out.

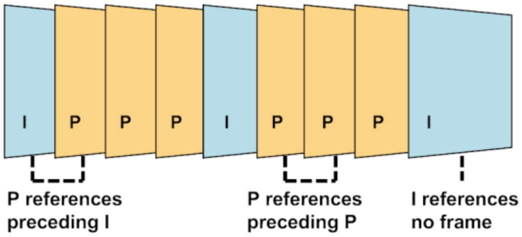

Figure 8: I and P frames in a compression algorithm

Comparison of compression standards

There are many video compression algorithms available, many of which share similarities. Popular compression schemes for flight test include MPEG2 (used for DVD videos), H.264 (used for Blu-ray video discs and on some online streaming services such as YouTube) and JPEG 2000 (used in applications such as archiving, medical imagery and digital cameras). Some characteristics of these three compression algorithms are shown in Table 3.

Table 3: Comparison of popular airborne compression standards

Standard	**MPEG 2**	**H.264**	**JPEG 2000**
Lossy/lossless	Either	Either	Either
Intra frame support	Yes	Yes	Yes
Inter frame support	Yes	Yes	No
Compression rate for good video*	Low	High	Medium
Suitability for continually changing scene at a fixed bitrate	Low	Medium	High
Resilience to transmission errors	Low	Variable	High
Processing overhead	Low	High	Medium

* For aircraft surface monitoring or other application where scene doesn’t change rapidly

In a scheme such as H.264, it is possible to only have I frames which effectively makes the codec inter only and perform very much like JPEG 2000. In this case however, because JPEG 2000 is optimized for intra-frame redundancy, better quality will be achieved for a given bit rate. This is also true if a scene contains constantly changing imagery (e.g. looking at moving landscape). However, if a scene contain intra frame redundancy and if bandwidth is limited, H.264 is more suitable. A compression algorithm such as MPEG 2 is only advantageous if low processing power is more important than quality at a given bitrate.

Compression advantages

Using a modern video compression/ decompression algorithm (codec) to exploit redundancies can result in a HD video stream that can be compressed down to <10 Mbps. Thus bandwidth and recording capacity required to handle compressed video can be over 100 times less than for raw video, often without a great loss in quality. This compression can be performed by a video multiplexing unit, however the unit will need to be powerful as it must be capable of handling multiple high bandwidth inputs and perform compression on these. Thus the unit is likely to be expensive, large and heavy.

An alternate solution is to perform the compression at source i.e. in the cameras. This has the advantage of splitting the compression task into less complex sub-units that inherently scale with the number of cameras used. This also means that there is no longer any need for a dedicated video multiplexor or management unit. Using Ethernet as the data transfer standard, a COTS switch can be used to route the packetized video data to the destination devices. Ethernet has the additional benefit of allowing packets to be filtered so a standard PC can be used to 'switch' camera source onboard as well as monitoring other FTI parameters.

A key benefit of such a camera design is that the onboard compression and packet based transmission facilitates multiple compression streams. This is particularly of use for flight test instrumentation where being able to define two compression rates for the same channel over the same Ethernet connection allows the user to set one data rate for the recorder and a second data rate for PCM transmission (Figure 9).

Filtering in the switch, either by port or by packet header, routes lightly compressed data (e.g. 8Mbps video data) to a recorder while highly compressed data (e.g. 1Mbps) is sent to a PCM bridge for telemetering. As a result, the video recorded is of good quality and high resolution whereas the video sent over PCM is of a lower quality, but still useful for real-time analysis. This allows the user to save on PCM bandwidth and send multiple video signals on a single telemetry link and have access to higher quality video data for post-flight analysis.

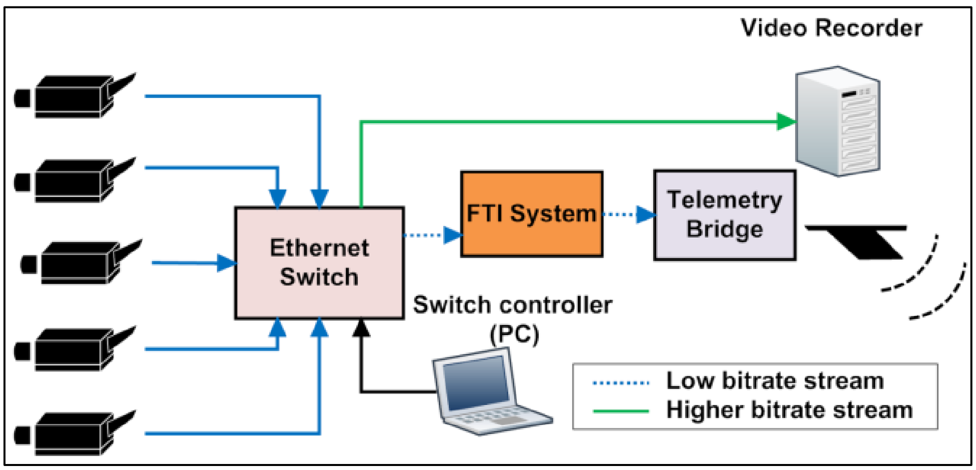

Figure 9: Dual compression on FTI cameras

Time stamping, such as the IEEE-1588 Precision Time Protocol (PTP), can be used to synchronize the video packets with other parameters in the FTI system. The PTP contains accurate information (typically to within 100ns) about when the data was acquired. It accounts for latencies across the network (for example through layers of switches) without adding significant extra overhead to the packet's size. With such a synchronization scheme, the difficult and time consuming task of correlating video imagery with other data becomes trivial using industry standard software tools.

IRIS AIRBORNE CAMERA

The IRIS airborne camera (Figure 10) was developed in line with the analysis of the future high-definition video needs for flight test applications. The design is rugged to survive the environment and takes account for the image capture needs in flight test applications (e.g. global shutter over rolling shutter).

The H.264 compression algorithm was selected as it was determined to have the best quality to bandwidth characteristics for the anticipated usage. FTI engineers are interested in viewing the aircraft and therefore likely to be pointing the camera at surfaces, landing gear and so forth which are scenes which typically contain inter frame redundancy. The desire to telemeter video pushes the focus to high compression rates, and in this situation H.264 is more suitable than a standard such as JPEG 2000. Additionally the flexibility of I to P frame prevalence means engineers can adjust this compression-to-robustness ratio to best suit the expected telemetry dropout rate.

The solution of compressing two channels of video at different rates is considered a good solution to the absence of high speed telemetry links. Until such time as these are widely available, the PCM bandwidth will inevitable limit the real-time quality of video data. However, although the real-time data isn’t the HD quality many are now used to at home with HD TV’s and content, a 1Mbps video stream compressed with a modern codec and properly optimized for the application will deliver good quality. Having a higher quality copy recorded onboard the aircraft means post-flight analysis can view details traditional SD cameras didn’t provide.

The use of an industry standard time synchronization protocol (PTP) was considered a necessary addition in an industry which is shifting inevitably towards an Ethernet backbone. Using common standards means it can be seamlessly integrated with data acquisition and recording systems which also use these standards. Removing the compression out of a data acquisition system or a dedicated unit, means the camera can be connected directly to an Ethernet switch. As there is no need for dedicated hardware compression, SWaP (Size Weight and Power) is minimized and installation wiring greatly simplified.

Figure 10: The IRIS airborne camera from Curtiss-Wright

As with Ethernet switches and network recorders, the camera can be set up and configured using the same data acquisition software reducing time and effort in configuring the system. As far as the software is concerned, the camera is just another data acquisition node.

Another advantage of using an industry standard and widely adopted video compression scheme is that commercial off-the-shelf software can be used to replay the data, in addition to simplifying integration with standard flight test replay and analysis software.
Other useful features adopted for flight test applications include;

- Different Lenses of focal length between 4.8 mm and 35 mm
- Full HD 1080P color (1 to 30 fps)
- RTSP, RTP and iNET-X compliant dual video streaming
- Unicast as well as Multicast Streaming
- High quality Kodak CCD sensor with global shutter imager

CONCLUSIONS

Flight test applications benefit from cameras designed specifically to meet the application and environmental requirements. Such cameras perform more reliably and integrate with other FTI better than consumer products which were not designed for the task.

Video cameras are moving from SD to HD which presents issues for existing video system solutions. Transmitting raw video adds complexity and limits the amount of video frames that can be transmitted and stored. Synchronizing this video data with other flight test parameters can also be a challenge. Dedicated compression cards can solve some of these issues but they have implications for SWaP.

Ethernet cameras with integrated compression aim to address these issues with dual output streams to suit recorder and telemetry applications, capabilities to switch video streams in an Ethernet switch and synchronization between FTI and video data. The use of simple and consistent setup software and off-the-shelf technologies facilitate quick and easy deployment.