Focusing on the Future of Airborne Imagery: IP Cameras

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Flight Test Instrumentation (FTI)

HD cameras

IP cameras

Image sensors

Introduction

As legacy airborne cameras are rapidly becoming obsolete, designers, systems integrators and end users have sought up-to-date digital video alternatives that offer higher quality images. Older cameras typically use coaxial wiring which is fairly immune to noise and is generally well understood, but it is heavy and can create installation headaches. In addition, the move to high definition (HD) also adds complexity and limits the number of video frames that can be transmitted and stored without additional conversion hardware.

One solution to this complexity is to use IP cameras that utilize Ethernet wiring, switches and recorders. Often such infrastructures are already installed on the craft for other data acquisition purposes. Ethernet IP cameras offer several benefits, such as simplifying installation and lowering system weight while providing high quality images. This white paper explores image capture technology and IP cameras, and investigates the merits of an Ethernet-based camera system compared to traditional Composite Video Baseband Signal (CVBS).

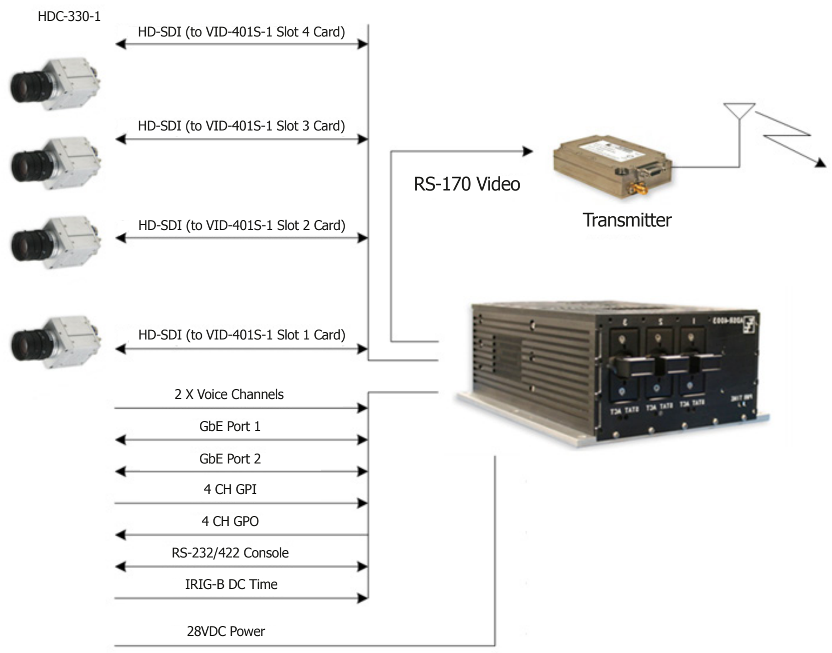

Figure 1: Camera networks usually include a recorder and the ability to telemeter data to a ground station.

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Using Cameras in Test Applications

Video is often used during a test campaign as a virtual "witness" to events (excluding high-speed video which is used for applications such as time magnification and trajectory analysis). It is generally not used as a primary data source for measuring phenomena about the aircraft, but it is a very useful tool nonetheless. When the image data is properly correlated with data from other sensors, busses, etc., one can correlate the physical event with imagery. This is especially useful for environments, like the cockpit, for example, where you can see how the pilots and operators are interacting with instruments and controls for user interface analysis and training (e.g. an organization may be looking at reaction times). Another example is to check that the instruments are displaying the same information as the bus to confirm the data the pilot is getting is accurate.

Many customers now want better quality video than older SD cameras offer. They also want cameras that can cope with being pointed into bright objects (such as the sun). Older cameras tend to use Charge-Coupled Device (CCD) sensors that suffer from pixel bleed and become washed out when encountering bright objects. However, transmitting raw HD video adds complexity and limits the number of video frames that can be transmitted and stored. Synchronizing this video data with other flight test parameters from a Data Acquisition System (DAS) can also pose a challenge. Dedicated compression cards can solve some of these issues, but they have negative implications for size, weight and power (SWaP) – all critical factors for FTI.

The extreme environmental conditions typical of FTI applications require highly reliable cameras ruggedized far beyond the levels supported by most industrial or commercial cameras. Today, a typical FTI system designer uses separate camera and video compression systems, or stand-alone video cameras, with simple recording capability. The video is not usually synchronized to other cameras or DAS data.

For flight test applications, camera data for telemetry needs to be coherently synchronized and available for storage. Ideally, the data in the telemetry stream should be highly compressed to minimize downlink bandwidth. Recorded data, on the other hand, should be minimally compressed to provide maximum quality for onboard and post flight analysis.

Camera Functions and Features

Various image-processing functions are essential for delivering the appropriate image quality during test flights. Rolling shutter cameras, common in consumer cameras, capture an image frame by rapidly scanning vertically or horizontally, but the time difference between different parts of the frame can result in the distortion of moving elements (such as spinning rotor blades) as shown in Figure 2.

For flight tests, where the subject being imaged is rotating or moving with high velocity, a 'global shutter' is required to eliminate this smearing effect (Figure 2). Global shutters, which use simultaneous acquisition to capture the entire frame in a single instant of time, eliminate motion-induced distortion. Rolling shutters are generally cheaper, however, and can perform better at low light levels, so they can still be useful in some applications.

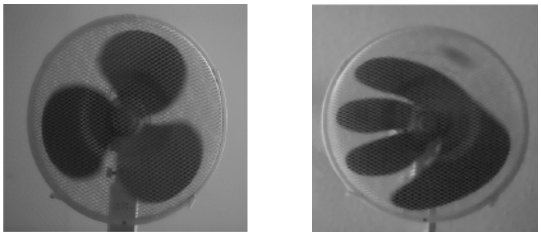

Figure 2: Global shutter (clear) and rolling shutter (distorted)

The more modern CMOS sensors used in many HD cameras today are immune to pixel bleed that CCD sensors suffer from. They can also commonly utilize Wide Dynamic Range (WDR) techniques to enhance the illumination of a scene. WDR techniques identify particularly bright and dark portions of images and control the saturation of pixels in those areas. WDR is important for achieving good image quality and is becoming common in commercial electronics such as cameras and TVs (WDR is often referred to as HDR is these applications).

Environmental Factors and Conditions in FTI

During flight tests, the aircraft must execute maneuvers not often encountered during typical operation. The aircraft and its systems must be pushed to their limits to prove the validity of the design assumptions and to record the safe operational limits. Cameras for FTI must be designed to meet stringent and harsh environmental requirements in order to withstand the extreme vibration, shock, humidity and temperature. For example, an FTI camera may need to operate on a runway at 50ºC, and shortly afterwards at -30ºC. Such thermal differences can change electronic component impedances as a result of temperature or moisture condensation.

FTI cameras should have rugged optical windows made of sapphire glass, for example, to protect against scratches and breakage. And they should feature ruggedized connectors to maximize the camera's availability. To ensure that environmental requirements are met, the camera should be qualified to DO-160, MIL-STD-461, MIL-STD-464, MIL-STD-810 and MIL-STD-704 at certified laboratories. Manufacturer testing, quality management (ISO 9100, EN/AS 9100), and other manufacturing standards (IPC-A-610 E, IPC-A-600, IPC J-STD-011, IPC/WHMAA-A-620) need to be addressed during the design stage.

Cameras in FTI Applications

FTI camera data is typically sent to ground via a telemetry device, and to a recorder. Full HD video at 60 fps can take up to 3 Gbps of bandwidth per channel. If several HD cameras are required the bandwidth required for uncompressed video can overload the data acquisition system. Also, the transmission bit rate will affect the video quality. Lowering the bit rate will reduce the video quality unless the frame rate is decreased.

To maintain video quality, changing the frame rate has a linear effect on the suggested bit rate. Video compression is one method for overcoming some of these problems.

Figure 3: Video data can contain significant redundancy

Compressing HD video using an industry standard algorithm can reduce the bandwidth to a more reasonable amount without significantly affecting the image quality. Today's popular compression schemes for flight test include MPEG2 (DVD videos), H.264 (Blu-ray video discs and online streaming), JPEG 2000 (archiving, medical imagery and digital cameras).

Table 1 displays a comparison of popular airborne compression standards. H.265 is a newer standard that is similar to H.264 but offers about double the data compression ratio at the same level of video quality (or higher quality at the same bit rate). It is not yet common in airborne imaging due to its higher processing requirements.

TABLE 1: Popular Compression Standards

	MPEG2	JPEG 2000	H.264	H.265
Lossy/Lossless	Either	Either	Either	Either
Intra frame support	Yes	Yes	Yes	Yes
Inter frame support	Yes	No	Yes	Yes
Compression rate for good video*	Low	Medium	High	Very high
Suitability for continually changing scene at a fixed bitrate	Low	High	Medium	High
Resilience to transmission errors	Low	High	Variable	Variable
Processing overhead	Low	Medium	High	Very high

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

A camera that supports onboard compression and Ethernet packet-based transmission can easily output multiple compression streams over one link. It can do this by creating two data streams, each of which stores video data in Ethernet packets. One set of packets can contain high bit rate data, the other low bit rate. This can be particularly useful for FTI. For example, two compression rates can be defined for the same channel over the same Ethernet connection, enabling the user to set one data rate for the recorder and a second data rate for Pulse Code Modulation (PCM) transmission. Having this multiple video stream output from the camera has the significant advantage of removing the need for separate video compression devices.

TABLE 2:	SUGGESTED BIT RATES						
		BIT RATE WITH NO NOTICEABLE ARTIFACTS		BIT RATE WHERE SOME ARTIFACTS POSSIBLE*		BIT RATE WITH NOTICEABLE ARTIFACTS	
RESOLUTION	ENCODED FRAME RATE	H.264	H.265	H.264	H.265	H.264	H.265
½ D1 (352x288)	30	1 M	0.5 M	0.7 M	0.4 M	0.3 M	0.2 M
D1 (720x486)	30	4 M	2 M	2.5 M	1.3 M	1 M	0.5 M
VGA (640x480)	30	3.5 M	1.7 M	2 M	1 M	1 M	0.5 M
SXGA (1280x1024)	30	15 M	7.5 M	9 M	4.5 M	4 M	2 M
HD 720 (1280x720)	30	10.5 M	5.2 M	6.5 M	3.2 M	1.5 M	0.7 M
HD 720 (1280x720)	20	7 M	3.5 M	4.5M	2.2 M	1 M	0.5 M
HD 1080 (1920x1080)	30	24 M	12 M	14.5 M	7 M	6 M	3 M
HD 1080 (1920x1080)	20	16 M	8 M	9.5 M	4.5 M	4 M	2 M

*Suggested bit rates for encoding without any noticeable artifacts, with some motion artifacts, and with noticeable artifacts.

IP cameras are not ideal for every application however. Perhaps an aircraft is already wired up for cameras using coaxial cables and the effort to rewire isn't worth the benefits. Another reason is the engineers may be very familiar with older SD cameras and prefer to stick with this option rather than implementing a new technology. While it is attractive to normalize all data into Ethernet with the same timestamping standard, there may be a separation in teams who look after the imaging side of a test campaign who don't have perfect data correlation as an objective. It is therefore more likely that IP cameras will become most widespread in new programs where they offer significant benefits from the start by simplifying aircraft wiring and hardware needs.

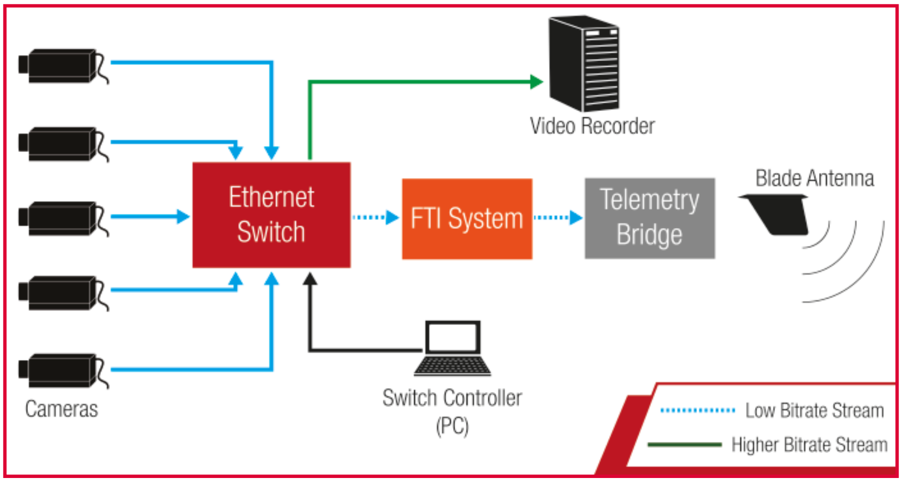

Figure 4: Dual compression on FTI cameras

Video Transfer and Playback

Moving from the more traditional analog camera data to a packetized format requires a paradigm shift. One is now moving data, not video, so you'll need something that can read the data to display it. One tactic is to wrap industry standard image data in such a way that it can be unwrapped into an easily readable format for industry standard displays. Recorders can store Ethernet data easily – any pain in terms of displaying this data will be in the software, and this is relatively trivial as long as you're using the right formats.

Latency is an important issue for replaying data. Currently, a software solution that can parse video from Ethernet data (such as the widely used Video LAN Client (VLC)) may take a second or two to display what the camera has captured. While this is not a big problem for ground personnel who are looking at the feed, it can be an issue for those in the air. A pilot may be examining or trying to control an object in real-time and the feedback delay between their actions and the information on the screen can be jarring.

To achieve lower latencies, one needs to process data as quickly as possible in the encoder and decoder. This may have an impact on image quality depending on the required bit rate and movement in the scene. For example, if a high quality reproduction of a complex moving scene is required, the processing overhead is going to be larger and more time consuming than a lower bitrate stream of a static image. One way to reduce latency significantly in most applications is to implement a hardware decoder, as opposed to software. This would likely reduce the time impact of decompression from approximately 1 second to 60 ms.

A common requirement for airborne displays is to show multiple camera images on one screen. For traditional cameras, such displays require a multiplexer to do the physical switching of the signals. This means extra hardware and a lot of wiring which increases system weight. An advantage of IP cameras is that they produce multiple streams and their data can be "logically" routed. Physical routing requires dedicated hardware to take the signals and direct and/or combine them, whereas logical routing uses the existing Ethernet switch network to route packets to a recorder, display, processing system, and transmitter as required.

Curtiss-Wright's IP Camera Eco-System

Curtiss-Wright provides proven HD cameras that can be integrated with our wide range of FTI system solutions. Our IP cameras support full HD resolution (1920 x 1080p) at 60 fps and can support multiple video streams. We support the video codecs MPEG2, H.264 and H.265. In addition, our IP cameras also output SDI and CBSD at the same time as IP data for legacy support and interfacing with existing equipment.

Our cameras are also low latency and draw a lower than typical amount of power thanks to their low power FPGAs and removing the need for dedicated compression and routing hardware within a system. They are also capable of being controlled over the network via SNMP commands. Using the existing Ethernet infrastructure eliminates the need for extra control wiring and also allows commands to be issued from the ground via an IP radio. This opens up a lot of possibilities as envisioned by the iNET standard that is now finding its way into hardware.

We also timestamp the data at the source – when the image is captured, the frame itself is timestamped rather than the data being time stamped at a recorder for example. This means that the image data can be perfectly time-correlated with other data that is captured.

Summary

There is demand for higher quality video for airborne applications such as FTI. Ideally, such new camera solutions can reduce the weight and difficultly of installing wiring, and allow for data to be coherently combined with image data. Ethernet cameras can address these needs with in-built compression and multiple output streams. Additionally, as Ethernet-based networks have become the dominant choice for FTI applications, we see increased requirements for integrating Ethernet-based cameras with FTI data acquisition equipment, network recorders, and telemetry devices as this removes duplication of wiring and devices.

Using an Ethernet camera that supports onboard compression enables video compression to be removed from the DAS (or eliminates a dedicated unit). The camera

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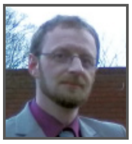

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can be connected via an Ethernet switch directly into the system, like any other data acquisition unit. Even better, because there is no need for dedicated hardware compression, SWaP is minimized and installation wiring greatly simplified.

Curtiss-Wright has been providing HD cameras into airborne applications for years, and our IP camera solutions meet all current requirements, as well as supporting future technologies such as H.265 compression and iNET style remote control.

Learn More

Product: HDC-330 Airborne High Definition Camera

White Paper: The Need for Speed: Using Photogrammetric Analysis with High-Speed Cameras in Flight Testing Applications

Case Study: Organization Successfully Verifies Object Trajectory Using High Speed Cameras