USING PHOTOGRAMMETRIC ANALYSIS WITH HIGH-SPEED CAMERAS IN FLIGHT TESTING APPLICATIONS

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ABSTRACT

Flight test engineers sometimes need to conduct photogrammetric analysis to investigate transient phenomena and validate computer and wind tunnel models. Data is captured to characterize the performance of the aircraft and its avionics and other equipment and for store separation tests. Store separation encompasses such functionality as fuel tank release, landing gear operation and missile deployment. To capture accurate visual data during flight tests requires the use of a high-speed camera device capable of capturing moving images with exposure times for each image of less than 1/1,000 second or frame rates in excess of 200 frames per second.

The cameras used in store separation FTI applications must be very environmentally rugged and perform optimally and accurately in harsh environments. Any potential failure must be mitigated because of the high cost of keeping a test platform in the air. Post-test, it is important that the images can be correlated so the data is suitable for photogrammetric analysis. This paper discusses what is required for successfully capturing data in flight tests for photogrammetric analysis and outlines a high speed camera system solution.

INTRODUCTION

Flight test engineers encounter situations where they need to use photogrammetric analysis to determine how objects, surfaces and mechanical systems perform. This typically requires capturing images at high speed from multiple angles, often in harsh environmental conditions. Post-test, it is important that the images can be correlated so the data is suitable for photogrammetric analysis. This white paper will discuss what is required for successfully capturing data in flight tests for photogrammetric analysis and outlines a high speed camera system solution.

CAPTURING DATA IN THE BLINK OF AN EYE

Flight test engineers sometimes need to conduct photogrammetric analysis to investigate transient phenomena and validate computer and wind tunnel models. Data is captured to characterize the performance of the aircraft and its avionics and other equipment and for store separation tests. Store separation encompasses such functionality as fuel tank release, landing gear operation and missile deployment. To capture accurate visual data during flight tests requires the use of a high-speed camera device capable of capturing moving images with exposure times for each image of less than 1/1,000 second or frame rates in excess of 200 frames per second.

The cameras used in store separation FTI applications must be very environmentally rugged and perform optimally and accurately in harsh environments. Any potential failure must be mitigated because of the high cost of keeping a test platform in the air. The camera is primarily used for recording fast-moving objects as digital images onto a storage medium. After recording, these images can be played back in slow motion to examine the motion for scientific study of transient phenomena.

Early high-speed cameras used film to record high-speed events, but have been superseded by entirely electronic devices. These modern cameras use either a charge-coupled device (CCD) or a CMOS active pixel sensor that typically record all images to internal DRAM memory. In general, these cameras offer more features and reliability than their film counterparts – particularly in harsh environments.

BUILDING A NETWORKED IMAGE CAPTURING SYSTEM

The elements of an integrated system solution for photogrammetric analysis of store separation would typically include a high-speed camera, a network-based camera manager unit, a managed network "core" switch, other network switches, a networked data recorder and a multifunction camera control panel unit. The core switch serves as a network fabric to pass message packets from cameras or other sensors located around the aircraft.

High-speed cameras are more common today thanks to the advance of imaging technology and the widespread adoption of digital camera technology, particular in mobile phones (many of which now have high-speed video modes). However, while many high-speed cameras are available, and indeed many switch and recorder products can be readily purchased, not all cameras and ancillary equipment is suitable for flight test applications.

One key issue is correlation of data. Video or camera images should be time-stamped to ensure images from different cameras can be compared accurately during analysis. To ensure accurate time-stamping, the FTI system should provide a grand master clock. In the case that older PCM networks are present, the PCM data can be converted into to modern Ethernet packets by gateway devices on the FTI system.

The FTI network engineer also typically programs the cameras and sensors in advance of the test flight to assign triggering events and direct where in the FTI system the resulting data packets will be transferred. It is advantageous, therefore, to have an Ethernet-based camera manager reside on the network and orchestrate all of the triggering events. The resulting image data, which is first stored on the camera itself, can then be archived by sending to a network recorder or transferred to discrete memory in the camera. Because every image frame gets time-stamped by the FTI data acquisition unit or by the high-speed camera, it's possible after the flight or mission to accurately combine and synchronize all of the acquired data.

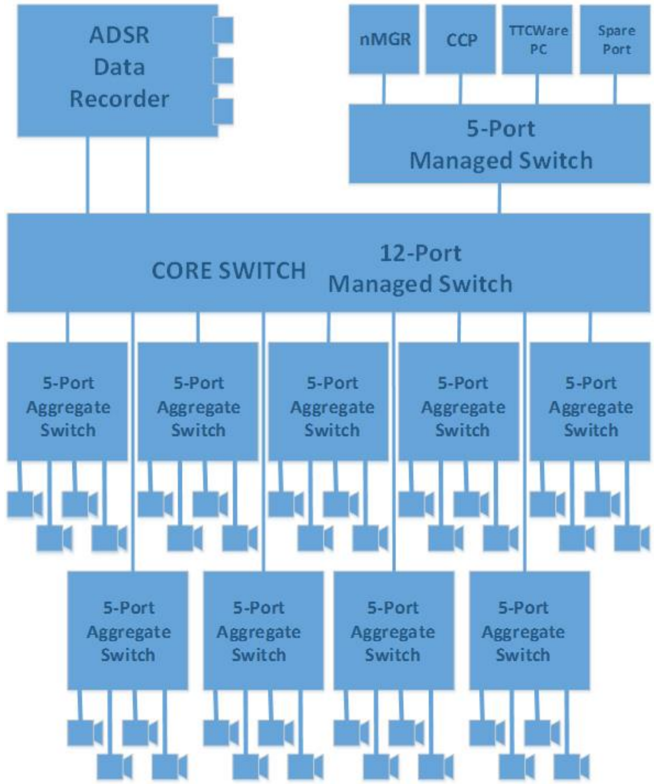

Figure 1: High-speed cameras are often connected into larger networks to capture events from multiple angles

Another key issue is ensuring the cameras are capable of operating normally in extreme environmental conditions. While many cameras on the market may be suitable for different climates and for extreme sports or industrial applications, few are able to work optimally while experiencing extreme vibrations, shock, temperatures, rapid temperature and humidity changes and fluid ingress.

VALIDATION AND PHOTOGRAMMETRIC ANALYSIS

Validation of state-of-the-art store separation prediction techniques is required to complete FTI studies for airborne certification programs. The use of photogrammetric high-speed camera missions enables the validation of the store separation prediction model by capturing six-degree-of freedom motion data. Photogrammetric analysis requires obtaining measurements from individual digital images to analyze the precise position and orientation of objects in three-dimensional space during a test flight.

In many cases, wind tunnel experiments will be performed in advance to generate the prediction model, which helps to minimize program risk. The FTI engineer correlates the quantitative data from the separation testing with the actual flight test results to validate the models. This data is measured when the stores are within a defined volume of analysis while on the test vehicle.

Typically, flight clearance authorities request measurement accuracy on the order of a few inches for proper correlation.

For example, when a missile is jettisoned from an aircraft in flight, photogrammetric triangulation techniques are used to quantify the missile's spatial position and orientation. This enables the weapon's displacement and attitude to be quantified after it has been released or launched from the aircraft. Such information is typically used to validate the accuracy of a prediction or to determine if the characteristics are “safe” enough to proceed to more severe release conditions.

To accomplish this type of photogrammetric analysis, several calibrations of the test equipment must be performed to quantify details such as the camera location and any lens aberrations. The goal is to ensure that the high-speed cameras are operating at 200 frames per second with exposures operating at 0.005 seconds per frame. The lens calibration process simply maps out any distortion in the lens, such as pin-cushion or barrel distortion, and determines how the projection of the object's image onto the camera Global Shutter CMOS image sensor is affected. Lens calibrations are performed by aiming the camera at a calibrated target.

In addition to calibrating the lens, the test objects, in this case the aircraft and stores, also have to be “targeted.” Targets are easily identified points (either integral to the object or placed on the object) at known positions with respect to a coordinate system. While only three targets are required for a photogrammetric solution, many targets are usually affixed to ensure that the minimum number will be available. It is imperative that the targets be visible by as many cameras as possible.

An initial orientation of the camera must also be obtained following fixing the position of the camera's image sensor plane. This orientation (the direction the camera is pointed with respect to the axes of the aircraft) will be used as initialization data in an iterative computer algorithm to determine precise camera orientation for photogrammetric analysis using a precise, common time reference such as the IRIG (Inter-Range Instrumentation Group) or IEEE-1588 PTP protocols. The PTP techniques allow cameras and other devices to synchronize their time base to within a few hundred nanoseconds. Synchronizing system components to a common time base enables simplified system designs and simplifies wiring – especially important for minimizing size, weight and power requirements (SWaP) on test aircraft.

During a typical stores release, images are recorded on a frame every 0.005 seconds. Since the camera axis orientation and the target's image position in the image sensor plane is known, Snell's law and compensations for known lens distortion can be applied. This enables a vector to be established from the image sensor plane through the lens to the target. If two or more cameras of known position have vectors from their image sensor plane to the same target at the same instant in time, triangulation can be used to determine the target's position in the aircraft coordinate system.

Software tools are now available that can read the image data and perform much of this analysis. These can facilitate simple tracking of objects where position, velocity and acceleration can be calculated with various tools and templates streamlines this process even more. Such applications are used commonly in crash test analysis for the automotive environment as well as many airborne and ground military test applications.

Figure 2: A Network-Based High-Speed Camera

CONCLUSIONS

Compact, lightweight and rugged cameras are ideal for a number of airborne applications, including stores separation, missile deployment and landing gear analysis – from manned aircraft or UAVs. When used with motion analysis software, high-speed cameras provide users with the ability to conduct in-depth, quantitative analysis of their high-speed images. Software solutions can support automatic tracking of up to three targets and calculates for velocity and acceleration.