IDAPS MULTI-CAMERA STORE SEPARATION ANALYSIS USING CAD-BASED MODELING

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ABSTRACT

The Image Data Automated Processing System (IDAPS), developed by the 96th Communications Group Test and Analysis Division at Eglin AFB, uses a CAD-based image matching technique to calculate a 6DOF trajectory of a store separation event. The system has been used successfully for single camera release sequences, but needed to be extended for multi-camera releases. This is vital for bomber missions where several cameras are needed to cover a store separation event.

KEYWORDS

CAD, OpenInventor, Store Separation, 6DOF, IDAPS

INTRODUCTION

Store separation is an important area of study for the Air force's aircraft compatibility certification process. It is conducted to ensure the safe in-flight release of various stores such as munitions and fuel tanks. It is vital to ensure the safety of the aircraft and pilot by guaranteeing a safe release trajectory that will put the weapon in a position most likely to achieve a successful mission. Since many aircraft-store combinations exist, a significant amount of modeling and testing is conducted as part of the certification process.

The Image Data Automated Processing System (IDAPS) is used by the 96th Communications Group, Test and Analysis Division for photogrammetric post-flight test store separation data collection and analysis. IDAPS has evolved many times over the last two decades to accommodate changes in technology and mission characteristics. The latest upgrade, to include CAD-based modeling and color imaging, is complete and has been proven accurate for single-camera processing. This paper will discuss the next phase of development that focused on extending the capability to include multi-camera processing.

IDAPS DESCRIPTION

IDAPS is a data reduction and analysis workstation developed to obtain trajectory information from a store separation mission. It is composed of a high-end graphic workstation and a custom software application. Inputs to the system include a digital image sequence, lens calibration information, and a mathematical model of a store. From this, a time-tagged 6 degrees of freedom (DOF) store separation trajectory is produced by superimposing a wireframe model over each frame of a digital image sequence.

The system is hosted on an HP xw9300 workstation running Red Hat Linux. The display hardware consists of an NVIDIA Quadro FX3400 PCI Express graphics card and dual 24 inch monitors. The application software was developed in C and FORTRAN and has a standard X-Windows GUI. CAD rendering is accomplished via Open Inventor, which is a platform-independent object-orient toolkit built on OpenGL.

IDAPS uses a database-like structure to manage image sequences from one or more cameras. The image file format used by the system is standard multi-TIFF, which many digital cameras can produce directly. Otherwise, images are pre-processed by a TrackEye workstation. TrackEye can read several digital camera formats-including those already being used in flight tests such as ASVS and Phantom. It is able to import and export a wide variety of digital image formats including TIFF, AVI, JPEG, and MPEG2. It is also equipped with a scanner that can digitize 16mm and 35mm film.

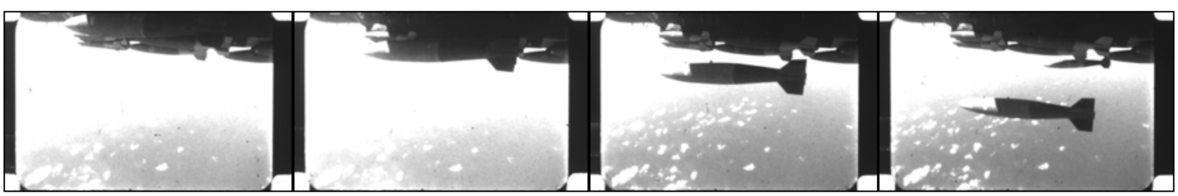

Figure 1. Image sequence

To calculate the optical characteristics of an image sequence such as its field-of-view and center of optics, a calibration process must be conducted for each camera/lens combination. A calibration image is obtained by photographing a wire-frame cube, of known size, aligned parallel to the camera focal plane. The calibration image is digitized and the four edge locations (each) of the near and far planes are read by the user. The system then uses a photogrammetric algorithm to determine coefficients used for depth and scaling.

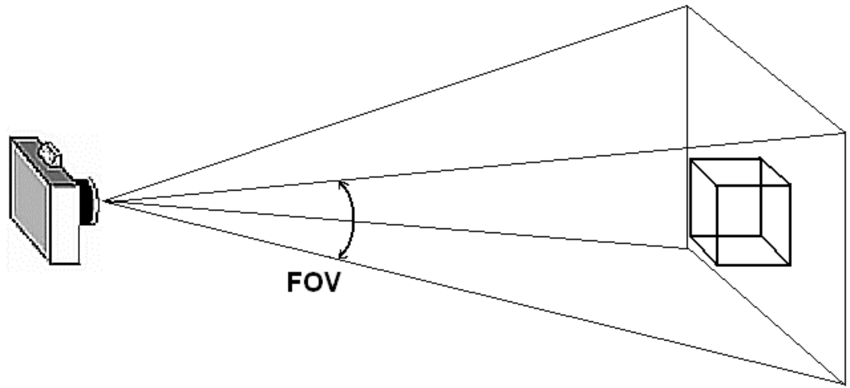

Figure 2. Lens calibration to calculate field-of-view

Many of the stores read by IDAPS are available in CAD format and can be obtained from the manufacturer. Usually they are modeled in a popular commercial format and need to be simplified, transformed, and converted into the Open Inventor format. This is accomplished using a COTS software tool such as Unigraphics, Rhinoceros, 3DExploration, and ivfix. The conversion is a one-time process and the modified models can be reused with multiple missions.

To avoid obscuring the detail of the item to be matched in the image, the CAD model is rendered as a silhouette with hidden lines removed. This drawing format provides an outline of the model's prominent features that are only visible from the point of view of the camera. Solid and wire-mesh polygon rendering is available to the user as an option for testing and demonstration.

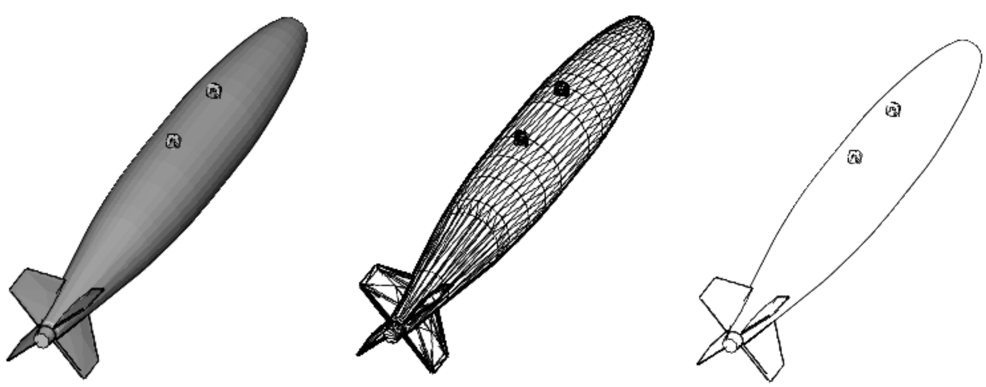

Figure 3. Solid CAD model (left), wire-mesh (center), silhouette (right)

The process of determining the position and orientation of a store is accomplished by superimposing a wire-frame model of an object over a digitized image. The model is manipulated through 6 degrees-of-freedom using GUI controls until the model matches the store in the scene. The system performs the necessary translations, rotations, and scaling (all based on the lens calibration) to transform the model's 2D pixel-location into a 6DOF position. This is done for each frame of the image sequence.

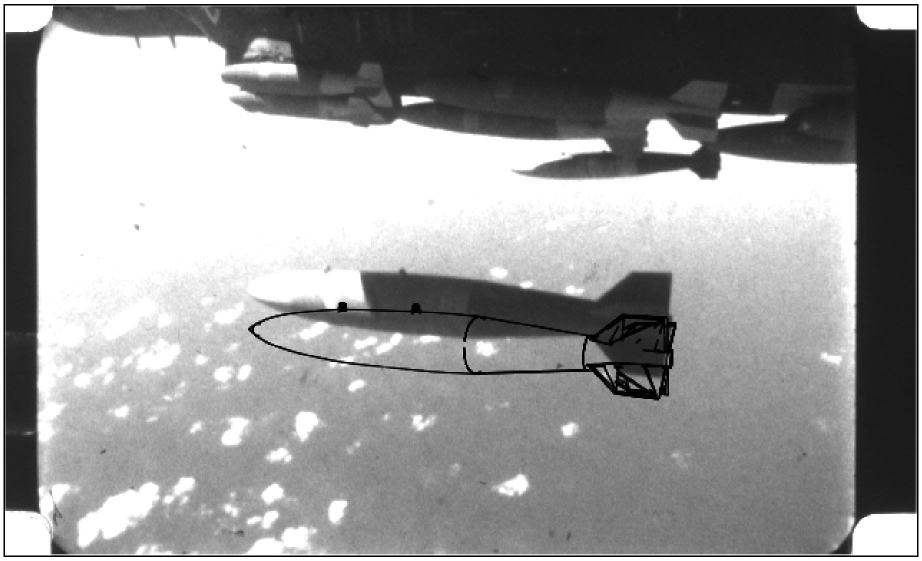

Figure 4. Digitized image of store with wire-frame model overlay

The process is user-intensive and requires a skilled operator with an aptitude for visual-spatial manipulation to quickly and accurately position and orient a 3-dimensional model rendered on a 2-dimensional computer screen to match a background image. Sufficient domain knowledge of store-separation is also required to give the user insight as to how the store will react during the release. Thus a user becomes proficient only after many hours of hands-on training and many years of operation.

SINGLE-CAMERA PROCESSING

For purposes of this paper, single-camera processing refers to reading store separation data from a camera when its location and orientation is not precisely known. This occurs most frequently on fighter aircraft missions where the decision has been made to not spend the time and expense of surveying the on-board cameras each time they are installed or adjusted on an aircraft.

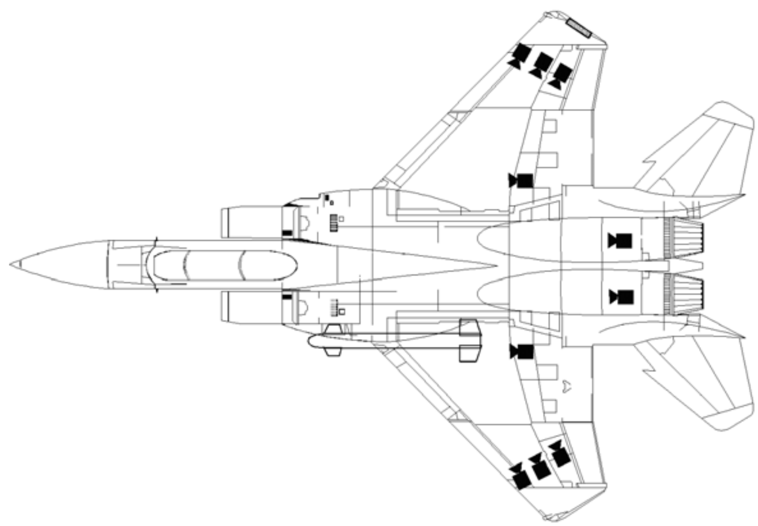

Figure 5. Sample camera configuration

Normally, a store-separation mission will be flown with multiple cameras, each capturing the event from a different perspective. The camera that will provide the best overall coverage is selected. Items to consider are: best picture quality, an un-obscured view, most stable, and most importantly the perspective that provides the best viewing angle to read the component of the store's trajectory that is most important to the store separation engineer. Most often inboard/outboard movement and yaw are closely scrutinized for safe store separations certification. Therefore, a camera view from the rear of the store is selected so that this movement will be parallel to the image plane where it easiest to visualize.

Once the camera view is selected, the initial frame is established. This is the frame where the store is at carriage just prior to release. The frame time and frame rate must be determined. If using a film camera, this is read from Inter-Range Instrumentation Group (IRIG) time coding on the edge of the filmstrip. If using a digital camera, timing information is either stored with the image data or provided separately.

The next step is to read the first frame and match the model to the item at carriage. It is important to get this frame correct because the readings from the following frames are offsets from the first. Thus, any errors are carried throughout the rest of the trajectory.

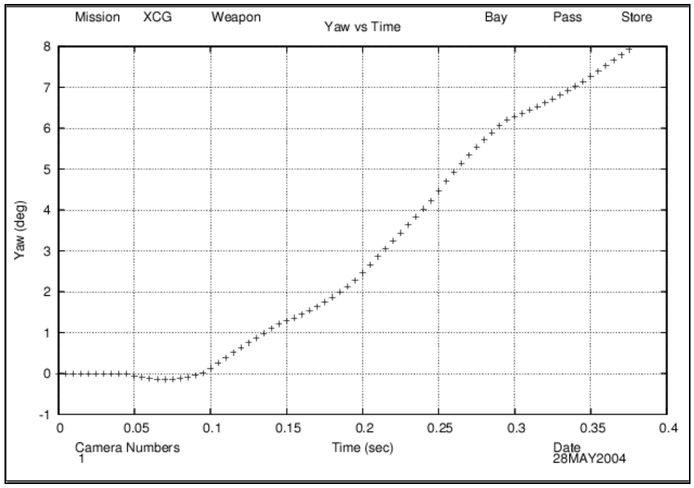

Figure 6. Sample plot of single trajectory component

In most cases, the frame-to-frame movement of the item is subtle and difficult to detect so typically the operator will read a subset of the frames (every fifth or tenth frame) and interpolate the unread frames. Then the image sequence is reviewed frame-by-frame to ensure proper fit and the model positions are adjusted where necessary

MULTI-CAMERA PROCESSING

Multi-camera processing is necessary when a store separation event cannot be covered by a single camera. This is typically the case with bomber and certain modern fighter missions where the item is released from inside a bomb bay. Each camera view covers a different segment of a release. The readings must be transformed to produce a correlated solution.

It is important to have overlapping coverage to ensure that the entire separation event is captured and readings can transition from one camera view to another. The start time for each image segment must be known so that the camera footage can be properly tied together.

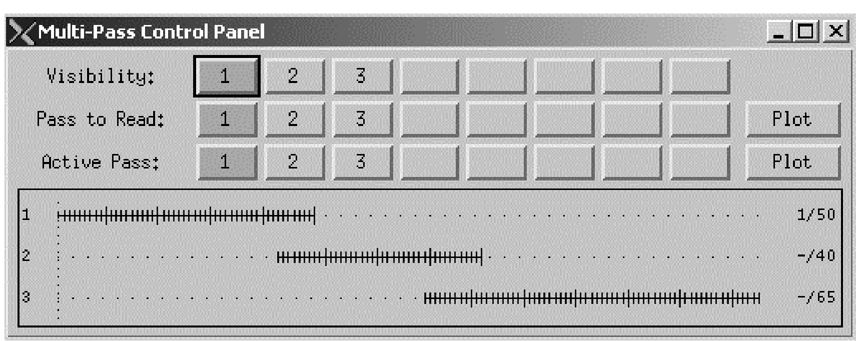

Figure 7. Multi-camera timeline with overlapping coverage for three cameras

In order for the coordinate transformation between camera views to be performed correctly, each camera's location and orientation must be known. Therefore the cameras must be surveyed as part of pre-mission setup. Additionally the location and orientation of the store at carriage with respect to the aircraft must be known.

The system will use the camera and store location information to position the model on the first frame of the first image segment, normally from the camera in the bomb bay. Since the model is rendered in pixel coordinates and the camera and carriage position are surveyed in aircraft coordinates, the system must perform the proper transformation and scaling to produce a good "fit". For that reason it is critical that the survey and camera calibrations are correct.

Figure 8. Multi-camera processing views

After the first frame, readings on subsequent frames of the first camera view proceed as described under Single-Camera Processing. The exception is where there is overlapping coverage; the model will be rendered on multiple camera views simultaneously. When the model is moved on one camera view, the model position is updated on the other views. After all frames of the first camera view are read, control is then transitioned to the next camera view and the process is repeated on each remaining view until the entire separation sequence is complete.

In order to produce a correlated solution, the readings from all camera views must be merged. Normally the cameras are synchronized to initiate recording at the same time, but the cameras may run at different rates and the frame times are not always time-coincident between cameras. Therefore, the merged-output trajectory data is processed via a cubic spline to produce a uniform interval output file.

CONCLUSION

At the time of this writing, the CAD-based IDAPS has successfully been in production for single-camera processing for several months and has proven to be a valuable asset for the 96th Communications Group, Test and Analysis Division. The addition of 3D CAD modeling has provided the ability to read modern feature-rich stores not possible with the legacy system. Development for multi-camera processing is complete and is undergoing system testing. After completion of this phase, future enhancements will include lens distortion correction, image jitter removal, and the reading of fin/wing deployment angles.

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