Automated Motion Imagery Exploitation for Surveillance and Reconnaissance

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ABSTRACT

Airborne surveillance and reconnaissance are essential for many military missions. Such capabilities are critical for troop protection, situational awareness, mission planning and others, such as post-operation analysis / damage assessment. Motion imagery gathered from both manned and unmanned platforms provides surveillance and reconnaissance information that can be used for pre- and post-operation analysis, but these sensors can gather large amounts of video data. It is extremely labour-intensive for operators to analyse hours of collected data without the aid of automated tools.

At MDA Systems Ltd. (MDA), we have previously developed a suite of automated video exploitation tools that can process airborne video, including mosaicking, change detection and 3D reconstruction, within a GIS framework. The mosaicking tool produces a geo-referenced 2D map from the sequence of video frames. The change detection tool identifies differences between two repeat-pass videos taken of the same terrain. The 3D reconstruction tool creates calibrated geo-referenced photo-realistic 3D models.

The key objectives of the on-going project are to improve the robustness, accuracy and speed of these tools, and make them more user-friendly to operational users. Robustness and accuracy are essential to provide actionable intelligence, surveillance and reconnaissance information. Speed is important to reduce operator time on data analysis. We are porting some processor-intensive algorithms to run on a Graphics Processing Unit (GPU) in order to improve throughput. Many aspects of video processing are highly parallel and well-suited for optimization on GPUs, which are now commonly available on computers.

Moreover, we are extending the tools to handle video data from various airborne platforms and developing the interface to the Coalition Shared Database (CSD). The CSD server enables the dissemination and storage of data from different sensors among NATO countries. The CSD interface allows operational users to search and retrieve relevant video data for exploitation.

Keywords: Video exploitation, Airborne reconnaissance, Mosaicking, Change detection, 3D reconstruction, GPU

1. INTRODUCTION

Airborne surveillance and reconnaissance are essential information for many military missions. Such capabilities are critical for troop protection, situational awareness, mapping and monitoring, mission planning and post-operation analysis / damage assessment. Video cameras are the most common airborne sensor payload as they are relatively inexpensive and light-weight. Both manned and unmanned airborne platforms gather large amounts of video data. However, using this data efficiently and advantageously is a challenge. How the imagery is used depends on the mission goals and at which stage of the mission it is used. Data collected must be reviewed quickly to support real-time operations in the field, whereas it is analyzed in more depth and over longer timeframes to support mission planning and intelligence gathering.

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In previous R&D projects [1][2] at MDA, we have developed a suite of tools that can process video data automatically, including mosaicking, change detection and 3D reconstruction. These tools have been integrated within a standard Geographic Information System (GIS) framework, offering a user-friendly interface suitable for both expert and non-expert users. The main objective of the on-going Automated Motion Imagery Exploitation (AMIE) project is to enhance these tools towards operational use, including the improvement of their robustness, accuracy and throughput.

ESRI ArcGIS [3] was chosen as the GIS platform for AMIE development. It is a family of products for visualizing, managing, creating, and analyzing 2D and 3D geographic data. ArcGIS is commonly used by military and other geospatial analysts. Therefore, developing on the ArcGIS platform minimizes the learning curve for these end-users, ensures these tools would fit into their current work process, and allows them to take advantage of other ArcGIS functionality while analyzing video imagery. While the AMIE tools are integrated within ArcGIS, the underlying tools are not dependent on ArcGIS and could be integrated into other GIS environments.

This paper gives an overview of the video exploitation tools developed at MDA and the on-going work in the AMIE project. Section 2 provides an overview of AMIE, and Section 3 describes the video exploitation tools in more detail. On-going work of the AMIE project is presented in Section 4 and Section 5 provides conclusions.

2. AMIE OVERVIEW

The AMIE tools currently support ArcGIS version 10 under Windows 7. After installation, the AMIE toolbar through which the operator can invoke the AMIE tools, appears in ArcMap. The high-level functionalities of the AMIE system are to ingest STANAG 4609 video from different platforms and allow the operator to visualize and process the video to generate the mosaicking, change detection and 3D reconstruction products, as illustrated in Figure 1. The platforms could be both unmanned platforms, i.e. Unmanned Aerial Vehicles (UAVs), and manned platforms, such as piloted airplanes and helicopters.

The AMIE system consists of several key modules as shown in Figure 2. The input STANAG 4609 video contains both the video data and the KLV meta-data. After the data has been ingested, the operator can play the video and visualize its footprint and aircraft path, provided by the meta-data. The operator can select the Region Of Interest (ROI) and hence the specific data to calibrate and from which to generate the various explotiation products, including mosaics, change maps and 3D models. These exploitation tools will be described further in Section 3.

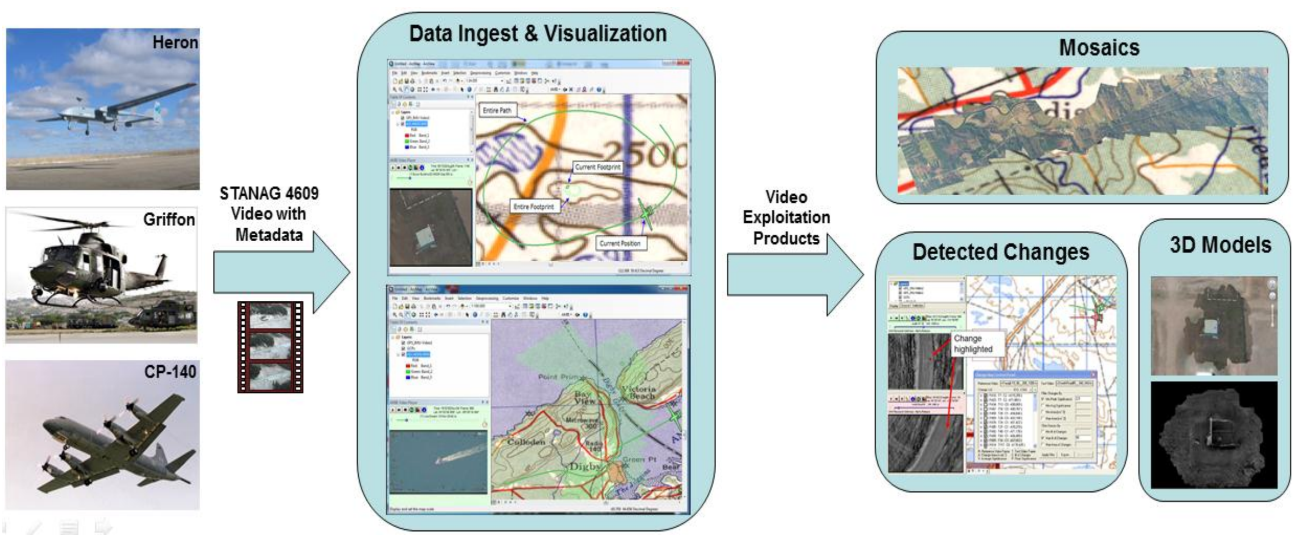

Figure 1 High-level Functionalities of the AMIE System (Image Source: DND, Map Source: DMAAC)

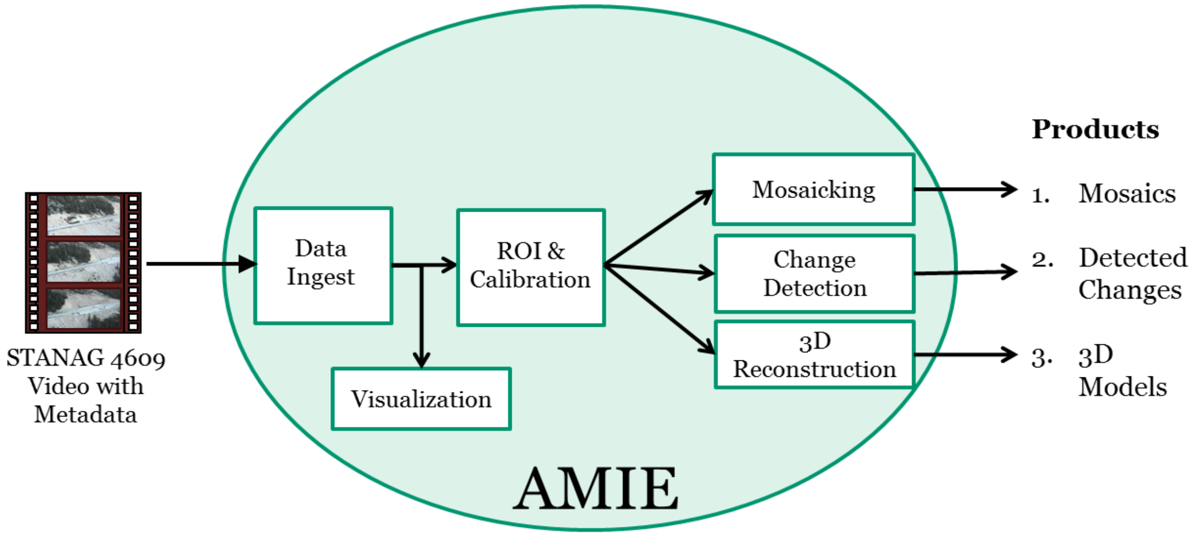

Figure 2 Key AMIE Modules

3. VIDEO EXPLOITATION TOOLS

3.1 Data Ingest & Visualization

The first step for the operator is to load a background map and specify the input video data to ingest into the AMIE system. The data ingest module extracts and interprets the KLV meta-data from the input STANAG 4609 video. The meta-data contains GPS, INS (Inertial Navigation System) information of the aircraft as well as the coordinates of the video footprint, etc. While many platforms collect STANAG 4609 compliant video, the video codec and the meta-data standard may still vary. For example, some may use MPEG-2 codec with EG 0104 meta-data standard, while others may use MPEG-4 (H264) codec with EG 0601 meta-data standard; all of these are supported by the AMIE data ingest module.

Visualization is a key component of the AMIE system, as it allows the operator to play the videos, see the aircraft path and the extent of the video footprint on a GIS map, which provides geographical context. The operator can then select the ROI and create exploitation products. The ROI selection is important as it allows processing on selected regions, which can greatly reduce processing time, especially when not all the imaged area in a video is of interest.

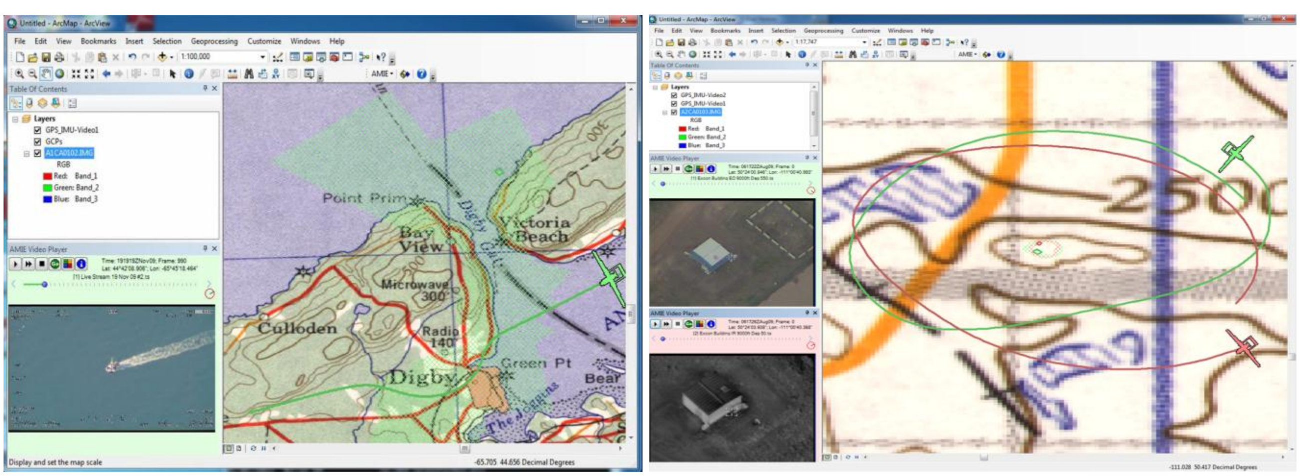

Figure 3 AMIE Video Player and Meta-data Display (Image Source: DND, Map Source: DMAAC)

Figure 3 shows the AMIE Graphical User Interface (GUI) front-end, which plays videos and displays aircraft paths and video footprints on the GIS map using the information supplied in the video meta-data (GPS/INS). The aircraft and footprint positions are animated while the video is playing. Up to two videos can be loaded into AMIE and visualized simultaneously, as shown in Figure 3 (right). This allows the operator to compare two videos and their coverage side-by-side, in particular for generating change detection products. The aircraft paths and footprints for the two videos are displayed in different colours and can be customized by the operator.

3.2 Calibration

Generation of video exploitation products require precise camera poses for the video frames in the chosen ROI. The GPS/INS meta-data in the STANAG 4609 video provides rough camera position estimate, which will be refined by the calibration process. Features are tracked between frames to obtain tie-points for bundle adjustment [4]. Stable features are highly desirable to produce longer tie-point tracks that provide better constraints for bundle adjustment. From the 2D tie-points and the GPS/INS video meta-data, bundle adjustment is performed to refine the 3D coordinates of these tie-points and the camera poses simultaneously.

The geo-registration accuracy of the products is limited by the GPS accuracy in the video meta-data. As video exploitation products have to be geo-referenced precisely to be useful for analysis, AMIE provides a Ground Control Points (GCP) marking facility which allows the user to mark additional correspondences between the video frame and the background map or an ortho-rectified satellite image, if desired, to improve on the geo-registration accuracy that can be achieved by using the meta-data alone. The optional GCPs serve as additional tie-points and are used during bundle adjustment. After the bundle adjustment, the calibrated video is ready for subsequent video exploitation, including mosaicking, change detection and 3D reconstruction.

3.3 Mosaicking

Individual video frames in a video sequence provide only a "soda-straw" view of a scene. Even if the user views many frames or the entire video, the user needs to rely on memory of the scene content to form a mental picture of the area that was surveyed by the sensor. Thus, it is very difficult to obtain situational awareness from just viewing the video data. The AMIE mosaicking tool helps to solve this problem by producing a high-resolution 2D geo-referenced image from the sequence of video frames contained in a video clip, for the entire video or the selected ROI, effectively showing the information from all the selected frames simultaneously, and thus providing better geographical situational awareness.

The AMIE mosaicking tool offers both quick-look and refined mosaicking options. For the quick-look mosaic, the video frames are stitched together based on the video meta-data only. For the refined mosaic, the video meta-data is first improved by calibration, after which the video frames are aligned and blended into a seamless mosaic. Figure 4 shows an example of a geo-referenced refined mosaic generated overlaid on top of a reference map to provide a high resolution up-to-date 2D image to the operator.

Figure 4 Refined Mosaic Generated by AMIE Mosaicking Tool (Image Source: DND, Map Source: DMAAC)

3.4 Change Detection

For scene monitoring applications it is important to be able to identify changes and anomalies. However, it is tedious and difficult for humans to compare hours of video clips looking for differences. The AMIE change detection tool automatically finds differences between two videos taken from two passes of the same terrain at different times. Changes between the two video files are identified and flagged on the video frames, so that operator attention can be utilized more effectively by focusing only on the detected changes.

The AMIE change detection tool offers a suite of filters to control the type of changes to detect, in order to both avoid overwhelming the operator with too many changes and to help the operator hone in to the attributes of the changes that are significant for that mission or scene. For example, the operator can control the intensity or size thresholds of the changes to be detected. Figure 5 (left) shows the change detection tool where two infra-red videos with the detected changes are displayed. The change highlighted by the red circle corresponds to an unknown object on a road: it is observed in the first video, but not in the second video. A change detection report can also be generated.

3.5 3D Reconstruction

For situational awareness, it is often easier to understand the scene by visualizing it in 3D. The AMIE 3D reconstruction tool can generate 3D models automatically, provided that the video frames contain sufficient texture. It creates calibrated geo-referenced photo-realistic 3D models, which can be viewed with common 3D GIS viewers. The models can be viewed from different perspectives, and allow distance measurements and line-of-sight analysis.

The AMIE 3D reconstruction tool processes the input frames in a pair-wise fashion and generates geo-referenced textured 3D meshes in KML format. The tool can handle both optical and infra-red data, which is valuable for night-time operations. Figure 5 (right) shows the photo-realistic 3D model in Google Earth, generated from a video that was captured while the aircraft flew around a building of interest.

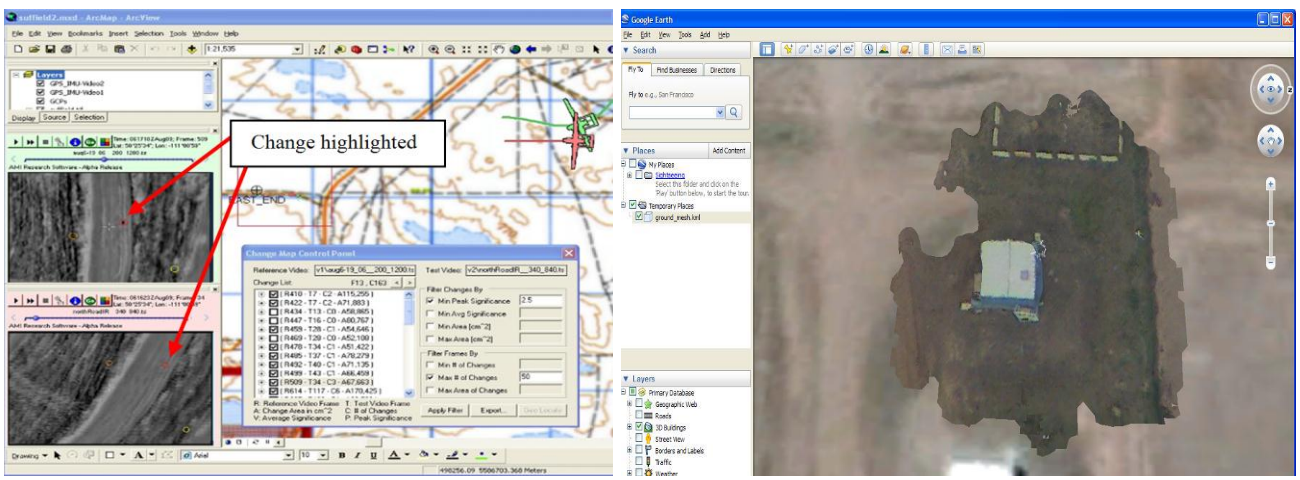

Figure 5 AMIE Change Detection Tool (left) and 3D Model Generated by AMIE 3D Reconstruction Tool (right)

4. ON-GOING WORK

In order to be ready for operational use, the AMIE tools need to be integrated with the current work flow of the analysts as much as possible and the tools should be user-friendly, robust, accurate and fast. This Section describes the key on-going activities in the AMIE project to achieve these goals. During this project, several iterations of the AMIE software are to be delivered to the selected end-users for evaluation. The feedback from the end-users is essential to improve the user-friendliness and the functionalities of the AMIE tools.

4.1 CSD Interface

The Multi-Sensor Aerospace-Ground Joint Intelligence, Surveillance and Reconnaissance (ISR) interoperability coalition (MAJIIC) project is a NATO effort to maximize the military utility of surveillance and reconnaissance resources for interoperability of a wide range of ISR assets. The common formats and exchange mechanisms employed in MAJIIC are based on NATO standardization agreements including STANAG 4609 for visible and infra-red motion imagery.

MAJIIC implements an interface based on STANAG 4559 to provide network-enabled architecture for enabling exchange of archived data, in particular, metadata-based search to retrieve archived data. The CSD enables the dissemination and storage of data from different ISR sensors among NATO countries. As one of the participating nations of MAJIIC, Canada uses the CSD and therefore one of the on-going AMIE activities is to interface with the CSD so that the AMIE tools would support the NATO standard and can be integrated better with the current work flow. This would allow operators to search and retrieve relevant video data from the CSD across the NATO countries to generate video exploitation products.

4.2 Robustness and Accuracy Improvement

The AMIE tools should be robust enough to handle most of the airborne motion imagery the analysts would like to process. For example, the video clips are often overlaid with text information and a cursor, which provide important information for the operators during data collection. However, such overlay is often burnt onto the video frames and presents a challenge to automatically processing video data. One of the on-going AMIE activities is to detect such overlay automatically to prevent those regions from being used during processing.

The video exploitation products should be accurate enough to be useful for mission planning and reconnaissance operations. Apart from supporting GCPs marked by the users, one of the on-going AMIE activities is to allow the use of a fine Digital Elevation Map (DEM) to help improve the calibration and mosaicking accuracy.

4.3 Throughput Improvement

While real-time processing is not a requirement, the AMIE tools should generate exploitation products relatively quickly to be useful. Apart from looking into algorithmic enhancements for speed-up, many aspects of video processing are highly parallel and therefore well-suited for optimization using parallel processing techniques. In order to identify the bottlenecks of the system, profiling is performed on the key AMIE components. The output profiling graph helps pinpoint the functions that are taking up the most processing time for optimization.

In recent years, Graphics Processing Units (GPU) have increasingly found use in non-graphics computation, towards general-purpose computing, and are now commonly available on computers. Once the bottlenecks have been identified, we can consider porting some processor-intensive algorithms to run on a GPU in order to improve throughput. The selected algorithms can be implemented in CUDA [5] which is supported by most of NVIDIA's modern graphics card. Recent literature have reported 30X speed-up using GPU for bundle adjustment [6] and 50X speed-up using GPU for mosaicking [7].

5. CONCLUSIONS

MDA has been providing Unmanned Aerial Vehicle (UAV) services to the Canadian and Australian forces in Afghanistan with the Heron, a Medium Altitude Long Endurance (MALE) UAV system [8]. While the Canadian services have completed, the on-going flight operations service for the Australian forces provides important surveillance information to commanders and front-line soldiers. Both unmanned and manned aircrafts gather huge amounts of video data, but it is extremely labour-intensive for operators to analyze such data. Our suite of fully automated video exploitation tools can aid operators in analyzing the large amounts of airborne video data collected to provide actionable intelligence, surveillance and reconnaissance information.

The suite of automated motion imagery exploitation tools have been integrated into ArcGIS to demonstrate a user-friendly tool-set that complements the GIS functionality provided by ArcGIS. Test results show that video exploitation products, such as mosaics, change maps and 3D models, are generated successfully from airborne video test data.

The on-going AMIE project is to improve the robustness, accuracy and throughput of these tools, and to better integrate these tools within an operational work flow. During the course of this project, several iterations of the AMIE software are to be delivered to the imagery analysts for evaluation. Training sessions as well as technical support are also provided to the end-users. Such feedback helps ensure the developed tools would meet the end-user requirements and would be useful to the analysts under real-world conditions.

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REFERENCES

[1] S. Se, P. Firoozfam, N. Goldstein, L. Wu, M. Dutkiewicz, P. Pace, JPL Naud, "Automated UAV-based mapping for airborne reconnaissance and video exploitation," *Proceedings of SPIE Vol. 7307: Airborne Intelligence, Surveillance, Reconnaissance (ISR) Systems and Applications*, Orlando, Florida, April 2009.

[2] S. Se, P. Firoozfam, N. Goldstein, M. Dutkiewicz, P. Pace, "Automated UAV-based video exploitation for mapping and surveillance," *Proceedings of International Society for Photogrammetry and Remote Sensing (ISPRS) Commission I Symposium*, Calgary, June 2010.

[3] ESRI ArcGIS, http://www.esri.com

[4] B. Triggs, P. McLauchlan, R. Hartley, A. Fitzgibbon, "Bundle adjustment – a modern synthesis, " *Proceedings of International Workshop on Vision Algorithms*, Corfu, Greece, September 1999.

[5] NVIDIA CUDA, http://www.nvidia.com/object/cuda_home_new.html

[6] C. Wu, S. Agarwal, B. Curless, S.M. Seitz, "Multicore bundle adjustment, " *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, Colorado Springs, June 2011.

[7] A. Camargo, K. Anderson, Y. Wang, R.R. Schultz, R.A. Fevig, "Real-time unmanned aircraft systems surveillance video mosaicking using GPU, " *Proceedings of SPIE Vol. 7668: Airborne Intelligence, Surveillance, Reconnaissance (ISR) Systems and Applications*, Orlando, Florida, April 2010.

[8] MDA Unmanned Systems, http://www.uavs.ca/