ADVANCES IN AERIAL IMAGE EXPLOITATION

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Abstract

The availability of low cost sensors, high bandwidth communication links and the growing popularity of Unmanned Aerial Reconnaissance Platforms like UAVs have resulted in dramatic new opportunities to conduct remote battlefield surveillance and reconnaissance missions from relatively safe Ground Control Stations. The sensors used in UAV explore the visible, infrared and microwave regions of the spectrum and the images are produced optically, electronically or by film.

Aerial Image Exploitation is an innovative image utilization program that uses multi sensor, multi resolution and multi spectral imagery obtained from Aerial Reconnaissance Platform for the purpose of Extraction, Exploitation, Dissemination and Interpretation of Imagery Intelligence. Research in aerial image exploitation is focused to provide a total solution of the problem by combining both hardware and software at the system and subsystem level. Major operational goal of image exploitation technology is to extract the vital intelligence from a large storehouse of available imagery by filtering those which are most likely to produce valuable findings, to combine classical image/signal processing techniques with technologies available in other fields and to use specialized hardware wherever required.

The first part of the paper describes the Ground Image Exploitation System and Imagery Intelligence Exploitation System being developed in ADE. The second part of the paper describes some of the basic and advanced research work being carried out in ADE, which is the backbone that lead to the development of these systems.

Some of the areas discussed in this paper are adaptive preprocessing of imagery, image mosaicing, terrain classification and high-resolution reconstruction of target region.

Keywords: Ground Image Exploitation System, Imagery Intelligence, Imagery Intelligence Exploitation System, adaptive preprocessing, mosaicing, terrain classification, high-resolution reconstruction

Introduction

Our Scenario consists of a UAV carrying multiple sensors and the endurance is 4 to 6 hours. Large volumes of imagery and data (meta data) are acquired during the mission. Ground Image Exploitation System (GIES), located at the Ground Control Station (GCS) of UAV, consists of commercial off-the-shelf hardware, open architecture and robust processing power to handle multiple tasks during mission simultaneously[1-6].

The system is provided with advanced imagery exploitation and efficient intelligent extraction capability to provide for the informational needs of surveillance and reconnaissance. Some of the features of the GIES system are telemetry data dynamically displayed with the imagery, map display with aircraft and target overlays, enhancement of gray level, color and IR imagery, instant computation of target geo-position, instant computation of target dimensions, creating video sequence of interesting target regions etc.

The output of GIES are the events executed during mission obtained in the form of screen shots, video sequence and text file containing image and target related information. This is available at the end of the mission as

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intelligent products called IMagery INTelligence (IMINT). IMINT is disseminated to a Surveillance Commander Station where it is further analyzed, interpreted and subjected to higher-level image interpretation tasks and fused with other auxiliary data sources in a system called Imagery Intelligence Exploitation System (IMINT-ES). The output of this system is used for long term planning and is a valuable resource for a wide range of ground information processing missions like generation of intelligent Knowledge Base of known/unknown terrain, strategic decision making etc.

**Ground Image Exploitation System**

The Ground Image Exploitation System (GIES) is developed to acquire, store, retrieve, process, analyze, display and disseminate information from imagery obtained during UAV mission [7]. GIES provides the intelligence officer, a control and monitoring interface required to ‘search’ and ‘acquire’ targets, process low contrast target imagery, calculate range and geo referenced target location, registration of image with survey map, measurement of terrain features, firing correction, data generation capability and dissemination of Imagery Intelligence to remote stations. GIES is located at the Ground Control Station of the UAV.

GIES is built on a high-end host PC with Embedded Vision Processor boards. GIES software is designed to perform multi tasking in multi threading environment. Graphical User Interface in the GIES shows the real time video, enhanced video using adaptive enhancement, dynamic display the mission related parameters in text and graphic form.

The provision for a ‘Search’ operation in GIES would enable the user to search the presence of an interesting target in a low contrast noisy mission area using an enhanced moving sub window. As soon as a target region is observed, the operation ‘Target Region Processing’ would subject the selected target area to multiple low level processing to help ascertaining the target. GIES operation ‘Target Calculation’ has the facility to acquire single or multiple frames containing the target and calculate the geo-referenced location along with the display of registered survey map.

GIES would enable the user to measure specific terrain features. The measurements include measuring linear distance on ground, tracing of curvilinear path, area coverage of an interesting terrain region and perimeter. There would be provision to calculate the fall-of-shot for artillery firing correction and display an enhanced sub-window around the target region and the region of fall-of-shot. Figs 1 to 6 show some typical operations in GIES system during mission.

Output of GIES is the IMagery INTelligence (IMINT) extracted during mission in the form of processed image, video stream with associated meta data of interesting regions and text files. This information is transferred to the Surveillance Commander’s station during mission using high-speed networking or it is available at the end of mission in the form of an intelligent report. Imagery Intelligence is a means for the Surveillance Commanders and staff of the combat team to view event pages and review short video clips of associated target related activities and perform further analysis and interpretation before the next mission.

Imagery Intelligence Exploitation System (IMINT-ES) will be located at the Surveillance Commander’s station. It shall be a platform for processing, analyzing and interpretation of results obtained during mission and to perform higher level tasks such as Change Detection, Multi Sensor Data Fusion, Terrain Classification, Target Region Reconstruction etc. Imagery Intelligence Exploitation System will be a stand alone PC with multi modal interfaces via talking, pointing and drawing.

IMINT Exploitation Systems shall process the imagery and the data acquired during mission. The Imagery Intelligence ensures the accurate and timely reporting of essential elements of information through the digital exploitation of multiple sources of imagery. High-level computer vision techniques, powerful image processing tasks, creation of geo-referenced intelligent database (DEM, Map, Satellite), extraction and storage of targets/areas of interest, computationally intensive algorithms, generation of elevation data for terrain models and utilization of intelligent information gathered during mission to create textual reports are the essential features of this system.

**Research Areas Related to UAV Image Exploitation**

**Adaptive Preprocessing of Aerial Imagery**

In the present scenario, images are acquired from an Unmanned Aerial Vehicle (UAV) on which two different types of sensors (Electro Optical and IR) are mounted. The imagery is acquired over a long period of time in various missions of UAV. The environment is unstructured and uncontrolled and neither the illumination char-
acteristics of the environment nor the surface characteristics of the terrain is known a priori. In addition, quality of the imagery is also affected by sensor characteristics (shutter speed, lens adjustment), dust, smoke and weather condition. An examination of the images obtained from the database of various missions revealed the need for adaptive preprocessing since the properties of these images vary to a great extent.

There are a large number of image preprocessing routines available in books and published literature [8-12]. Each of them has its own characteristics and does not produce desirable results for any input image. While a human image processing expert may select the best method on a case-by-case basis, such a human intervention is not feasible in practice. It is therefore necessary to devise methods to automatically select the best routines appropriate for the given input image [13-14].

The generic form for adaptive preprocessing scheme is shown in Fig. 7.

The main components of the system are the following:

**Mandatory processing module**: This module calculates from the image a number of characteristic parameters that represent the quality of the image and used for classification of the image.

**Method base**: This module consists of a repository of image enhancement routines. These routines perform low-level image processing operations and their goal is to identify features of interest.

**Knowledge base**: This module is developed offline and contains rules for the selection of appropriate enhancement routines. The rules are formed on the basis of the response of various classes of image being subjected to different enhancement routines available in the Method Base.

**Supervisor**: This module makes decision to select the enhancement routines based on the image class.

**Short-term memory**: This module is the working memory of the system and contains intermediate and final results that are yielded in the course of processing.

Input images after mandatory processing is passed to the supervisor, which on the basis of the image class looks to the knowledge base for the appropriate preprocessing modules. Method base contains a repository of image preprocessing routines which are invoked to operate on the image and the results are delivered to the short-term memory, which stores the final and the intermediate processing results.

In this paper, we have shown enhancement as one of the basic preprocessing methods and developed algorithm for adaptive image enhancement. An incoming image is first classified into one of several pre-determined set of classes. An appropriate enhancement method from a method-base is automatically selected based on RMS-error comparison with a typical parameter-vector constructed from a sequence of high-quality target images. Fig. 8(a) and (b) shows some typical result.

**Segmentation and Classification of Terrain from Aerial Imagery**

Classification of a terrain acquired by UAV is an important research area in Aerial Image Exploitation. The research work done at ADE proposes an automatic method for classification of terrain[15-16].

Image Segmentation, an important preprocessing step for image classification, involves partitioning the image into classes of meaningful areas (region) that are uniform and homogeneous and dissimilar to all spatially adjacent regions [17-19]. The selection of suitable feature is a critical part of an image segmentation process. The segmentation scheme proposes fusion of multiple image features such as intensity, texture and edge as a basis for segmentation. The results of segmentation is used for classification of four important regions in terrain viz., water bodies, bare land, forest and grassy areas.

An ideal segmented image should satisfy the following criteria

- region interiors should be simple.
- adjacent regions should have significantly different value with respect to the characteristics on which they are uniform.
- boundaries of each segment should be simple and spatially accurate.

The different steps that are needed to perform classification are: (i) Intensity based segmentation (ii) Texture based segmentation (iii) Edge detection (iv) Correction of the texture boundary (v) Classification.
In Intensity segmentation, homogeneity of the region is measured by gray level similarity. A pixel-wise image segmentation scheme using a multi resolution pyramid is used to generate the intensity-segmented image. Since structures may be present in an image at different scales, computation is done using a multi resolution pyramid with linked structure [20].

In Texture segmentation, the textural features are calculated using statistics of geometrical attributes of connected regions in a stack of binary images obtained from the textured image[21]. The first step of the approach is to decompose a texture image into a set of binary images. For each binary image, geometrical attributes such as the number of connected regions and their irregularity are statistically considered.

In order to get a reliable boundary of the segmented image, the edge detected image using Nevatia - Babu operator [22] are used. The boundary between two adjacent regions is now made one pixel width after superimposing the edge image to the final segmented image. The factors on which success in texture analysis depends are the choice of textural features that can discriminate one region from another, selection of appropriate window size for computing textural features and finding a reliable texture boundary. Since the appropriate window size needed for texture computation is not known apriori, the texture segmentation are initially done from the input image using windows of various sizes such as (32X32), (16X16), (8X8) and (4X4). In each step, the difference between intensity and texture segmented images is computed and the window size which gives minimum no. of erroneous pixels is selected. The pixels which are not segmented uniformly by either intensity or texture segmentation method comprise the set of erroneous pixels. They have two components: one is the error in intensity segmentation that occurs due to averaging and the other is the error in texture segmentation that occurs due to error in texture computation near the region boundary. The difference image is scanned and regions of erroneous pixels of size (3X3) and above are identified. Texture computation of these regions is performed and the pixels are assigned the appropriate value of the texture class to which it belongs. This process is repeated for the erroneous pixels obtained from both intensity and texture segmentation.

In order to generate the database required to classify the terrain and validate the proposed algorithm, known samples are collected from a terrain covering an area of (50 Km X 50 Km). From these large number of samples, study of ground truth shows that the terrain consists of mainly 4 kinds of ground elements viz., waterbody, bareland, grassy region and forest area. Database of these 4 regions are generated by arbitrarily selecting sub windows from known samples and extracting textural features which are normalized for the purpose of classification. Fig. 9 shows a typical result of terrain classification.

Registration and Mosaicing of Aerial Imagery

Image mosaicing is the task of assembling individual frames in the video stream of data obtained from UAV. The results of image mosaicing correspond to a simulated wide view representation of a scene. The useful defense application for image mosaicing are in Airborne Video Surveillance for Change Detection, Site Monitoring and Activity Tracking.

The basic idea of image mosaicing is that when a video is captured at a sufficiently high rate, there is a significant overlap in the imaged area in the scene between successive images. If this overlap can be detected, it is possible to find out the appropriate geometric transformation required to paste these two contiguous images to obtain an image covering a larger area of the scene. The above process can be continued till all frames in the sequence are merged to generate a single image of very large size [23-25].

Image Registration is considered to be the important preprocessing step for image mosaicing. It is the process of matching two or more images taken at different times from different sensors or from different viewpoints, so that the matched coordinate points in the two images correspond to the same physical region of the scene being imaged.

The following are the steps involved in Feature based Image Registration

1. Pre-Processing of images
2. Extraction of raw features
3. Reduction of feature space
4. Finding the Transformation parameters
5. Blending the images

In the present scenario camera is mounted on the UAV that captures continuous scene of the terrain and sends the information to the ground station. Since the camera mounted on the UAV is a forward-looking sensor, the
images have distortions due to perspective. The distortion becomes prominent at a shallow look angle. It is required to remove the distortions before the extraction of features. An 8- parameter affine model is used to find the perspective transform of the image. The images are then corrected and the output is stored in an appropriate file for feature extraction.

In this work, corner detectors are used for feature extraction. Corners are extracted using KLT and Harris corner detectors [26-27]. In order to obtain robust feature points, only feature points which are common to both the corner detectors are considered for matching. Due to the variation of illumination of the images, extracted feature points are not uniformly distributed throughout the image. This problem is solved by extracting the features in a multilevel Octree. In practice, often too many corner points are extracted and it is often necessary to restrict the number of corners before trying to match them. One of the well-known techniques is on the basis of cornerness and similarity.

Cornerness is the characteristic property of any interest point (feature point) \( P \) and is defined as

\[
C_p = \left| \lambda_1^2 + \lambda_2^2 \right|
\]

where \( \lambda_1 \) and \( \lambda_2 \) are the Eigen values of the intensity gradient matrix. To measure the correspondence between 2 points \( P \) and \( Q \) in two images, the similarity measure \( S(P,Q) \) is defined as \( S(P,Q)=\min(C_p,C_q)/\max(C_p,C_q) \).

A point is considered to be a good feature if \( S(P,Q) > T_c \) where \( T_c \) is a variable threshold. The other methods of reducing the number of feature points are by using threshold on the value of cornerness strength.

In order to determine homography, two pairs of feature points are chosen randomly from the image pair at a time[28-29]. The homography between the selected feature points is computed and the correctness of the computed homography is checked using a scoring module. This process is iterated until a good score is obtained or for a fixed number of iterations. The homography or transformation between two feature point sets when the transformation is a combination of translation and rotation involves four unknowns viz., translation in the x-direction \( T_x \), translation in the y-direction \( T_y \), scaling factor \( s \) and the angle of rotation \( \theta \) [4].

The angle of rotation

\[
\angle \theta = \frac{C_1 + C_2}{2s}
\]

where

\[
s = \frac{C_1 - C_2}{2C_1C_2 - \lambda_1^2 - \lambda_2^2}
\]

\[
\lambda_1 = \frac{C_1 + \sqrt{C_1^2 - 4C_2C_1}}{2}
\]

\[
\lambda_2 = \frac{C_1 - \sqrt{C_1^2 - 4C_2C_1}}{2}
\]

\[
C_1 = \max(C_1, C_2)
\]

\[
C_2 = \min(C_1, C_2)
\]

\[
C_p = |\lambda_1^2 + \lambda_2^2|
\]

\[
S(P,Q) = \frac{C_p}{\max(C_p,C_q)}
\]

\[
H = \begin{pmatrix}
-s\cos\theta & -s\sin\theta & T_x \\
s\sin\theta & s\cos\theta & T_y \\
0 & 0 & 1
\end{pmatrix}
\]

(1)

Let \( S_1 \) and \( S_2 \) be the two feature sets for which we need to compute Homography. The features in set \( S_1 \) are represented by \( L_1 \) and the features in the set \( S_2 \) are represented by \( R_1 \). Since there are four unknowns, two point correspondences are required. For a pair of corresponding matched points, the homography computation is done using the equations (1).

\[
H_1 = \begin{pmatrix}
L_1(0,0) - L_1(0,1) & 1 & 0 \\
L_1(0,1) - L_1(0,0) & 0 & 1 \\
L_2(0,0) - L_2(0,1) & 1 & 0 \\
L_2(0,1) - L_2(0,0) & 0 & 1
\end{pmatrix}^{-1}
\begin{pmatrix}
R_1(0,0) \\
R_1(0,1) \\
R_2(0,0) \\
R_2(0,1)
\end{pmatrix}
\]

(2)

The final homography matrix \( H \) can be written from \( H_1 \) as follows.

\[
H = \begin{pmatrix}
H_1(0,0) & -H_1(1,0) & H_1(2,0) \\
H_1(1,0) & H_1(0,0) & H_1(3,0) \\
0 & 0 & 1
\end{pmatrix}
\]

(3)

After obtaining the transformation parameters, images must be aligned to construct the mosaic i.e., overlaying one image on another. This composing process determines how the pixels in the overlapping region must be represented. In cases where image alignment is close to perfect, it is desirable to use all overlapping images to produce the mosaics. In this case, pixel values in the final mosaic can be computed by averaging the corresponding values of all candidate pixels of image frames that contribute in the generation of the mosaic.

Image mosaicing can be implemented in two different ways: sequential and tree-based. In the sequential approach, transformation between image 1 and 2 are calculated and are used to construct the mosaiced image1-2. In the second step, transformation between image1-2 and 3 are calculated and used to construct the mosaiced image 1-2-3. This process is repeated till the last image i.e., image \( n \) is mosaiced with image 1-2-3...n-1.
In the tree-based approach, for each image pair we construct a sub mosaic. After \( n/2 \) sub mosaic is completed, where \( n \) is the total number of images to be mosaiced, successive sub mosaics are taken and the transformation parameters between them are calculated. This process is continued till one final mosaic is obtained. Figs. 10(a) and 10(b) show mosaics generated using the above method.

Conclusion

The paper proposes the research work on Aerial Image Exploitation being carried out at ADE. The existing GIES system developed at ADE for UAV application has undergone large number of field trials. Currently an advanced version of GIES system is being developed which includes along with the GIES system at GCS, an Imagery Intelligence Exploitation System at the Surveillance Center.

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Fig. 5 Single frame target calculation

Fig. 6 Multiple frame target calculation

Fig. 7 Scheme for adaptive preprocessing

Fig. 8 (a) Input image (b) Output image after automatic selection of enhancement method
Fig. 9 Terrain classification (a) Input image  (b) Final classified image

Fig. 10 Mosaic generated from aerial video frames obtained from UAV
   (a) Sequential mosaicing  (b) Tree-based mosaicing