LOng Range Oblique Photography (LOROP) for Aerial Reconnaissance

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Abstract

Main advantage of LOROP is the reduced risk to the aircraft by enabling photography at higher altitudes and longer stand-off distances, thus distancing the platform from ground threats such as surface to air missiles (SAM). LOROP system can operate from a wide variety of platforms including supersonic fighter aircraft, business jets and maritime patrol aircraft at altitudes of up to 20 kilometers. Although the reconnaissance responsibility typically belongs to the military, there is a growing need to supply data to political and civilian decision-makers. Border control, counter-terrorism, smuggling interdiction are examples of national requirements which can be supported by reconnaissance systems, in particular real-time systems that can provide law enforcement authorities the ability to quickly react. Disaster assessment can be conducted on large scale, at day or night, in order to provide authorities the best information to make humanitarian assistance decisions.

INTRODUCTION

Airborne Reconnaissance's main objective is to collect ground / geographical information by deploying airborne instrumentation and to provide decision makers with this vital information to conduct appropriate operations on-line in real time. The information must be accurate, timely, continuous (day/night) and under adverse weather conditions. Current development in technology now allow a new generation of sensor systems (e.g. Charge Coupled Device, CCD) that address both real time data acquisition and data management. Aerial Photography is one of the major tools of airborne reconnaissance. Aerial photographs provide important information used for: Arial surveillance and routine reconnaissance, artillery adjustment and precision guided munitions designation.

LOROP is an airborne stand-off reconnaissance with real time data transmission or real time data record / transmit option, in pod (under-belly carriage) or nose mounted configurations. The reconnaissance pod houses the camera, comprising the refracting long focal length telephoto lens or Cata dioptric system or Cassegrain Ritchey-Chrétien telescope with a linear array of butted CCD detectors in the focal plane, the video processing unit and the scanning mirror.

The peripheral units, such as the data link transmitter, digital video recorder, air-conditioning unit, power supply and reconnaissance management unit, also reside in the pod. As an alternative to the podded installation, LOROP also offers an internal installation in which the reconnaissance equipment is mounted in the nose section of the craft in advanced configurations.

System control is performed from the cockpit. The collected imagery can be recorded in-flight and / or transmitted in real time to the ground station. The ground station incorporates the tracking antennas, data link receiver, image enhancement, archiving capability and hard copy soft displays.

CATEGORIES OF AERIAL PHOTOGRAPHY

Aerial photographs are taken from a variety of altitudes. The altitude ranges are defined as follows:

- Low altitude: 0 to 450 meters,
- Medium altitude: 450 meters to 3 km and
- High altitude: 3 km and above

Airborne reconnaissance photographic techniques can be broadly divided into the following two categories:

- Vertical photography
- Oblique photography

VERTICAL AERIAL PHOTOGRAPHY

Vertical aerial photography is accomplished with the camera held or suspended in the aircraft, so it points directly downward with the optical axis of the lens perpendicular to the ground. At the moment of exposure, when the camera is level and the film is parallel to the ground, the result is a photograph, for all practical purposes, with a uniform scale.

However, if the aircraft is climbing, diving, banking, or the camera is tilted for any other reason at the moment of exposure, the resulting photography does not have a uniform scale. It is always important in vertical aerial photography to hold the camera in a true vertical position.

The purpose of vertical aerial photography is to show details clearly of ground objects at a uniformly accurate scale. The major draw back of vertical photography is that the aircraft has to fly directly over the target and oftentimes cannot be employed to reconnoiter enemy territory or to survey certain types of terrain topography.

OBLIQUE AERIAL PHOTOGRAPHY

An oblique aerial photograph is made with the camera directed out and down at an angle from the aircraft. Oblique images do not have a uniform scale, and are divided into following two subcategories.

HIGH-OBLIQUE AERIAL PHOTOGRAPHY

High-oblique photography is accomplished at a camera angle that shows the horizon at about a 30-degree camera depression angle. It resembles the view a pilot sees when approaching the target. High-oblique photographs are useful in guiding pilots toward a photographic target, a bombing target, or a helicopter-landing site. High-oblique photographs are also used for orientation purposes because large areas are covered. A high-oblique photograph provides a true perspective view of land surfaces. It is easier for a person on the ground to locate and identify objects in a high-oblique photograph than in a low oblique or vertical photograph.

LOW-OBLIQUE AERIAL PHOTOGRAPHY

Low-oblique photography is accomplished at a camera depression angle of about 60 degrees. A low-oblique photograph covers a relatively small area. Subjects look more familiar than in a vertical photograph. It is normally used for identification purposes of the target. Horizon and not Aircraft altitude is a determining factor in whether an oblique is classified as high or low. Horizon is visible in high oblique but not in low oblique photographs.

ADVANTAGES OF OBLIQUE PHOTOGRAPHY

Oblique photography technique enables the imaging of enemy territory from well inside the own countries border and to study enemy’s troops deployment from a safe distance. It is also useful in monitoring of landslides. Conventional vertical aerial photography often does not show the detail necessary when monitoring landslides. Landslides that occur in canyons are difficult and dangerous to try to photograph from conventional platforms. With the advent of CCD and digital image processing techniques, oblique photographic images can be processed & decisions can be taken in real time. It has become an essential reconnaissance tool both for offensive and defensive maneuvers.

REMOTELY PILOTED VEHICLES (RPV)

Remotely Piloted Vehicles (RPV) represent an emerging technology for actual defense applications, virtually all the type missions performed by manned aircraft can be envisaged for RPV's by is a much reduced size and weight system.

This poses a challenge to the equipment designer because the systems must show good performance, under adverse weather, light conditions. For mobile operations, defense users of RPV's require a small light weight air frame and pay load which may be launched and recovered from un-prepared sites.

SMALL FORMAT CAMERA SYSTEMS – 70MM

Prior to the 60’s most reconnaissance information was obtained mainly by frame photography which limited the area viewed by frame size and field of view [1]. The small format cameras with 70mm image format were used mainly for low to medium altitude reconnaissance and strike applications [2]. 70 mm panoramic camera allows lateral coverage from horizon to horizon along the flight path. The other application of camera includes its ability to permit the evasive maneuvering of strike aircraft while still obtaining critical strike photography. 70 mm small format camera systems offer high resolution in small format. In order to compete with large format and long focal length cameras 70 mm camera should have large field of view and high resolution optics [3].

70 mm panoramic camera was designed and developed successfully using a 76.2 mm, F/2.8 lens covering a 75 mm image format. The camera was designed and developed for film as detector covering 400 nm – 700 nm. The camera covers field of view of 180^0 x 41^0 and has optical resolution of 40-60 cycles/mm at high contrast. In brief 70 mm panoramic camera offers a cost effective option for low and medium altitude reconnaissance.

SMALL FORMAT CAMERA SYSTEMS – 35MM

The use of small format camera (35 mm mini panoramic) for airborne reconnaissance and surveillance gained momentum during early eighties with the availability of new high resolution color and black and white films and greatly improved Opto-mechanical design & fabrication technologies[4]. Traditionally large format cameras with 9" and 4.5"x 4.5" and 70 mm image format with long focal length lenses were commonly used for aerial reconnaissance and surveillance since World War II. But the use of state-of-art optics and film technology made small format camera photography acceptable for reconnaissance.

The availability of limited space in RPV's and unmanned platforms further increased their acceptability for the purpose of airborne reconnaissance and surveillance. The other advantages of small format cameras include their small size, weight and power requirements.

Miniature panoramic (Minipan) camera was designed and developed successfully using a 50.8 mm, F/2.3 lens covering a 35 mm image format for RPV's. In its initial version this camera was designed and developed for film as detector covering 400 nm – 700 nm. In a later version film was replaced by CCD therefore optics was redesigned to cover broad spectrum from 400 nm – 1100 nm. This version made possible to obtain photograph both in visible and near infra red (NIR) portion of spectrum. The camera covers field of view of 180^0 x 34^0 and has optical resolution of 60-100 cycles/mm at high contrast.

Figure 1 shows the basic principal of panoramic camera operation [5]. The lens rotates about its own axis. The image is formed on the moving film as it passes through the variable slit. Since the film moves at twice the angular velocity of the lens and in the opposite direction, exposure times as short as 1/4000 seconds, at a frame rate of four frames per second are readily attained. Figure 2 shows a 35 mm Minipan camera designed and developed at CSIO Chandigarh

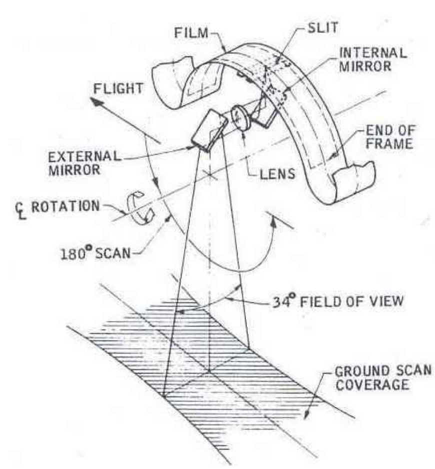

Fig. 1 Basic principle of operation of Minipan [5]

Fig. 2 Minipan Camera D&D by CSIO

WHY LOROP

Many countries have hostile neighbors even there is no open conflict but they really do not trust each other. This environment of mistrust demands constant vigil along the border and Line of Control (LOC) in order to monitor the troop movement and invasion by intruders from the other side of border. LOROP becomes the best source of information about the activities of their neighborer along the LOC. LOROP enables its user to watch enemy's terrain or their activities from safe standoff distances as far as 100 kilometers away. In the case of a neighboring country, one can fly several kilometers within one's own boarders while recording in great details installations on the other side of the boarder. Similarly, one can fly over international waters and observes activities along the shore and many kilometers inland [6].

LOROP can supply data to political and civilian decision-makers. Border control, counter-terrorism, smuggling interdiction are examples of national requirements which can be supported by reconnaissance systems, in particular real-time systems that can provide law enforcement authorities the ability to quickly react. Disaster assessment can be conducted on large scale, at day or night, in order to provide authorities the best information to make humanitarian assistance decisions.

FILM BASED LOROP CAMERAS

The heart of a LOROP is an objective, which forms the image of a part of the target on to film/CCD. Most film based LOROP cameras use refractive lenses to image the ground scene on the film [6**]**. Usually, the objective comprises of a number of lenses to minimize image degradation due to aberrations. Refractors allowed broad area coverage to be achieved from low altitude as such lenses could economically provide wide-fields-of-view.

A typical film based LOROP use a long focal length lens of Petzval type. The focal length of the lens is 66" or 1676.4 mm, with an aperture of F/4 and it covers an image format of size 4.5" x 4.5" [7]. The lens covers the whole visible spectrum from 400 nm to 700 nm and provides excellent performance as shown in figure 3.

CONVENTIONAL FILM Vs. CCD CAMERAS

CCD cameras allow real time reconnaissance. Electro Optical (EO) sensors (like CCD) utilize a wider spectral range (400 nm – 1100 nm). Signal contrast improved through haze subtraction. In EO cameras CCD is sensitive over a wide range of spectrum. In LOROP cameras the CCD sensor is operated in the push broom mode. The principal advantages of a CCD camera for use in air-borne reconnaissance are their inherent ruggedness, small size, low voltage operation and potential for low production cost once an impact base is developed.

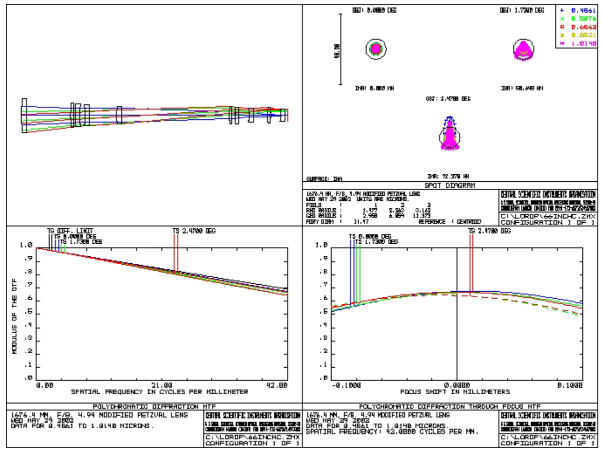

Fig. 3 66-inch (1676.4 mm) focal length f/4 dioptric lens for Itek's KA-120A Film based LOROP Camera

DUAL BAND LOROP

There is a worldwide trend to replace film LOROP cameras with dual-band EOIR (electro-optical infrared) systems **[Maver]**. Because film systems can only support daytime operations and require return-to-base and chemical processing before any intelligence can be derived.

Dual band LOROP provides simultaneous, multi-spectral imaging (IR and visible), capable of day and night operation, without any restrictions to the aircraft maneuverability or combat capability.

Although refractive optics can be used with electro-optical focal planes, normal optical lenses will not pass infrared energy. Thus, film cameras can be upgraded by replacing the film cartridge with CCD detectors, but only daytime imaging can accomplished with this method. An additional consideration is that a lens optimized for a film camera is rarely an optimum design for a digital E-O system. Spherical lenses can also be effectively replaced by aspherics to enhance performance.

The Cata dioptric system results in reduction in weight, compactness due to path folding and better chromatic correction. As longer-range performance is required today, designers of modern systems typically select Cata dioptric imaging system for dual band LOROP as shown in figure 4, an optical systems designed and developed by Recon Optical. A 110-inch (2756 mm) focal length f/5.6 Cata-dioptric lens design for a Recon/LOROP Camera is used with an EO Sensor.

MULTISPECTRAL EO LOROP CAMERA

Even Cata dioptric imaging system do not transmit light beyond 1100 nm, therefore, pure reflective imaging systems are designed to be used in VIS & IR spectral region. Mirror systems offer several benefits:

- Substantial savings of weight in large aperture, long focal length systems
- Mirror systems are more amenable to folding the optical path to reduce length and volume
- Less sensitive to thermal perturbations
- Mirror systems show no chromatic aberrations, thus allowing wide spectral bandwidths to be collected by a single optical system (e.g. visible and infrared)

Figure 5 illustrates the fundamental components of a dual-band LOROP. A common, all-reflective front-end optical system collects reflected (visible) and emitted (infrared) energy of the ground scene. A beam splitter behind the optics separates the visible and the infrared wavelength energy and directs each to their corresponding focal plane assemblies. There may be additional optics used in the individual visible and infrared optical chain e.g. field flattener lens.

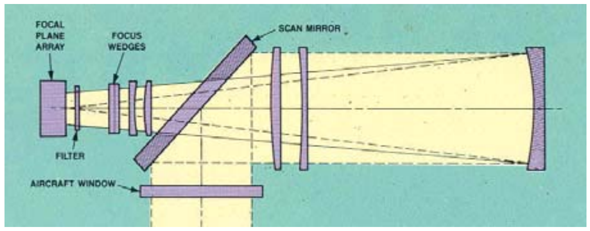

Fig. 4 110-inch (2756 mm) focal length f/5.6 Cata-dioptric lens for Recon’s CCD LOROP Camera

FOCAL PLANE ASSEMBLIES

Both line and area array focal plane assemblies are available to detect visible and infrared energy. Curiously, film has been used both as an effective area array and a line array in LOROP cameras.

In a framing camera, a single image could comprise a 4ºx4º field of view, exposed at one time onto film. Upgrading such film cameras to E-O, an area array CCD is used to maintain this same format. In push broom and sector scan (whiskbroom) cameras, film is continually exposed through a variable slit while the film travels behind it. Line array CCD’s employ the same operation, using variable Time Delay and Integration (TDI) to vary the effective exposure in like manner to the variable slit. Either a line or area array can be used to collect LOROP imagery. In a pan-scanning collection system, in which the sensor scans the ground scene perpendicular to the flight path.

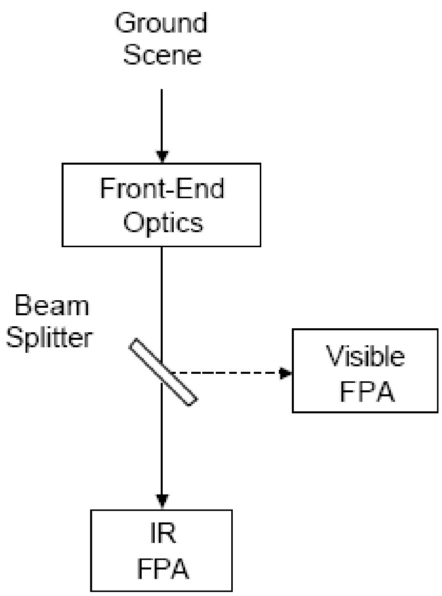

Fig. 5 Fundamental components of dual-band sensor using common front-end optical system [8]

IMAGE RECORDING/STORING

In LOROP, a multi-column CCD is generally used. Picture format, ground resolution required and the focal length of the image optics decide the no. of pixels and the size of each pixel to be used. It is possible at the cost of volume and weight for on-board recording.

EXPOSURE CONTROL

Three choices are available to change the exposure to compensate for varying light levels.

- Scan the scene at a slow rate

- Allow the change to accumulate in pixel for longer periods
- Use a TDI CCD.

EXPOSURE CONTROL USING A TDI CCD

A TDI CCD is operated so that the accumulated charge during one time in one TDI pixel is shifted to next one in its column. The charge is shifted in synchrony with a shift in the scene image to the next TDI pixel. Both the scene scan rate and the charge accumulation time remain constant, only the number of TDI pixels used in each column varies to change the exposure [9].

SCANNING METHODS

The imaging lens records a part of target at a time and using scanning techniques covers entire target area. EO cameras scan a scene by two main methods:

- Push-broom scanning
- Panoramic (Pan) scanning

PUSH-BROOM SCANNING

The CCD row of pixels is aligned across the line of flight in push-broom operation, and the image moves past the CCD as the aircraft moves forward through the air. The faster the air speed, the faster the image moves past the CCD. The CCD line time (exposure) must be less than the time required for the image to move across one pixel, or the resultant smearing would adversely affect the image quality.

Push-broom cameras, for LOROP tend to have only 2-3^0 of coverage of the crossed track. These cameras provide a strip image and cannot furnish stereo imagery and produce lower data rates.

Push-broom cameras facilitate easy mode of scanning and data handling at the cost of stereo imaging, wide coverage and speed constraints.

PANORAMIC SCANNING

Pan camera operation aligns the CCD pixel row parallel to the line of flight (cross-track). The scanning rate and the CCD line rate can be adjusted to limit image smear. LOROP pan cameras can provide 4-10^0 of cross track coverage and stereo imagery, and produce higher data rates.

SIGNAL PROCESSING

Due to asymmetric imaging geometry, oblique photos would have key stone error. Once the scene image has been converted to electronic signal levels, it can be corrected for pixel non uniformities and other image processing techniques may be applied to subtract the haze and amplify the signal level (contrast increased), the image can be digitally recorded or transmitted to the ground station.

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