INPE has been working in the development of a pushbroom type of sensor. The first prototype of INPE's pushbroom camera includes a commercial type optical system (Hasselblad lens) and a 1728-element CCD array (Fairchild CCD 122). In a preliminary evaluation, data acquired in the first flight was converted to digital form in order obtain both CCTs and film products for qualitative and quantitative analysis. A three bar ground target was used to study the geometric characteristics of the sensor system as compared to those of conventional aerial photographs, taken simultaneously during the same test flight. Analysis of the first results have shown that: (1) The sensor system met most of the specified characteristics for a prototype. (2) Aircraft (e.g. yaw) and image (e.g. smearing) motions contributed to the major geometric distortions. (3) Particularly, bright targets tended to show an enhanced effect of line to line misregistration (line to line shifts were mainly due to the lack of synchronization during the A/D conversion process). (4) Although a preset geometric resolution of 76cm (3000m - overflight) was not obtained, objects as small as 30cm wide were, radiometrically, resolved.
INPE'S LINE IMAGING CAMERA: PRELIMINARY RESULTS

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ABSTRACT

INPE has been working in the development of a pushbroom type of sensor. The first prototype of INPE's pushbroom camera includes a commercial type optical system (Hasselblad lens) and a 1728-element CCD array (Fairchild CCD 122). In a preliminary evaluation, data acquired in the first test flight was converted to digital form in order obtain both CCTs and film products for qualitative and quantitative analysis. A three bar ground target was used to study the geometric characteristics of the sensor system as compared to those of conventional aerial photographs, taken simultaneously during the same test flight. Analysis of the first results have shown that: (1) the sensor system met most of the specified characteristics for a prototype. (2) Aircraft (e.g. yaw) and image (e.g. smearing) motions contributed to the major geometric distortions. (3) Particularly, bright targets tended to show an enhanced effect of line to line misregistration (line to line shifts were mainly due to the lack of synchronization during the A/D conversion process). (4) Although a preset geometric resolution of 76cm (3000m - overflight) was not obtained, objects as small as 30cm wide were, radiometrically, resolved.

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1. INTRODUCTION

This paper presents a preliminary analysis of the first imageries obtained by a line imaging device developed by INPE. INPE's imaging devices is a line imaging camera or pushbroom type of sensor which includes a commercial optical system and a 1728-element charge couple device (CCD).

Most of the visible-near infrared imaging devices in the eighties will be of the pushbroom type. Among other advantages, the lacking of moving parts in these types of sensor well categorize them to orbital remote sensing. The actual line imaging camera of INPE is an airborne test prototype which in its first test flight already yielded imageries of reasonable quality. These encouraging results are the beginning of a series of experiments with line imaging devices which are planned by INPE. Therefore, this paper will focus on the analysis of the preliminary results, or pioneer imageries, obtained by INPE's line imaging camera.

2. IMAGING DEVICES

There are two main types of non-photographic imaging devices: frame imaging devices (matrix array) and line devices (linear array). Matrix array or frame devices for remote sensing purposes are still in their development stage and will not be discussed here (Figure 1).

Line imaging devices are sensors which generate an imagery on a line by line basis, and they can be divided into two basic types: scanning devices (E-M scanners) and self scanning devices (pushbroom or CCD-scanners).

Electromechanical scanners (E-M scanners) are second generation sensor which basically include a rotating mirror, an optical system and a focal plane where one or few detectors are laid down. The detectors are aligned in the focal plane parallel to the track or flight direction (e.g. Landsats). Scanning of a strip of the terrain is done by a rotating mirror which collects the energy from the ground scan in a cross track direction (Figure 1), that is, E-M scanners are optical-electronic-mechanical devices. Differently, self-scanning or pushbroom sensor types are optical-electronic devices which include an optical system and a focal plane where an array of detectors is aligned in the focal plane perpendicular to the track or flight direction (cross track). Scanning of the terrain is done by electronic sampling of the detectors via readouts of charge couple devices (CCD). Thus, while in an E-M scanner a line of an imagery is generated gradually by incremental movements of a mirror along the swath width, in self-scanning or pushbroom sensors the generation of a line of an imagery happens at once. In an pushbroom sensor type every ground resolution element along a line will be sensed by its "own" corresponding detector (Figure 2). This difference in architecture brings some advantages which are discussed next.

2.1 - E-M SCANNERS VERSUS PUSHBROOM SENSOR TYPES

One of the first advantages of self-scanning or pushbroom sensors is the lack of moving parts compared to moving mirror of E-M scanners. Thus pushbroom sensor types are not, in principle, susceptible to mechanical failures which make them attractive to orbital remote sensing. Imagery wise, pushbroom sensors simplify some tasks in on board and ground image processing such as image corrections due to mirror's movement, proper of E-M scanners (e.g. nonlinear mirror's movement, forward and reverse scans).

Inherently, the architecture of pushbroom sensors allows to explore different modes of data acquisition as for instance, a pointable sensor (e.g. look off nadir, stereo coverage). Additionally, linear array of detectors permits a longer dwell time for each detector; this allows to obtain better geometric (smallerIFOVs) and radiometric resolution (Chesteck, 1982). Therefore compared to E-M scanners, which reached their zenith in the beginning of this decade (Schnetzler and Thompson, 1979), pushbroom sensor types are leading towards small, low power, flexible, rugged and geometrically stable imaging devices. They will permit to obtain imagery with high photometric accuracy or data with high radiometric sensitivity at relatively narrower bandwidths (e.g. 0.5% for 20 nm bandwidths, Schnetzler and Thompson, 1979), and by reducing ground processing time, they will permit to deliver imagery more rapidly to the end user.
3. INPE's LINE IMAGING CAMERA

INPE's line imaging camera is a pushbroom sensor type which includes a transmissive optical system and an 1728-element array of detectors. A full description of this imaging device can be found in Siqueira et al. (1984). Imagery data acquisition was done through analog recording in a high density tape recorder (HDT), and later, data were converted to digital format and recorded on computer compatible tapes (CCTs). Film products were obtained using an electronic imaging recording device (EBIR).

4. IMAGERY ANALYSIS

Imagery material treated herein corresponds to airborne data acquired during the first test flight with the experimental imaging device built by INPE. Naturally, this consists of a preliminary analysis of preliminary test products. The major goal in a first test flight is a "proof of concept type of experiment". Accordingly, the analysis of the products of the experiment (i.e. imageries) are not final, but rather illustrative to the concept.

Data were acquired on February, 1984 using a turbo engine aircraft (Bandeirantes) at a nominal altitude of 3000m. Predicted swath width was 1316m (FOV=24.7°) and a corresponding ground resolution of .76m (Figure 3). The flight test took place over the São José dos Campos area including INPE's main campus. A soccer field was set as a reference area where black and white strips of plastic were laid down in order to form a three-bar target (Figure 4).

Original data recorded on board in high density tape (HDT) were converted to computer compatible tapes (CCT) and later transformed to hardcopies (film) through an electron beam imaging recording apparatus (EBIR). Imagery analysis was done both through an image analyser (Image-100) and visual inspection on films. Two imagery frames of 1728 by 1800 resolution elements (pixels) were selected for analysis, one corresponding to INPE's headquarter area and other including São José dos Campos urban area.

4.1 - IMAGERY GEOMETRY

As mentioned before, self-scanning imaging devices as opposed to E-M scanner are geometrically very stable since they do not include moving parts. However, imaging devices which generate a imagery on a line by line basis (i.e. line imaging devices) are very sensitive to the platform's stability, thus requiring platforms of high performance.

The overal geometry of the imageries obtained by INPE's line imaging camera shows a distorted pattern. This overall imagery distortion is a direct result of aircraft's unstableness as for example roll, yaw (Figure 5 and 6). To accomodate this main distortion it is necessary to built a gyro-stabilized platform in the aircraft or to develop dedicated image processing (e.g. Burton, 1977). Some line imaging devices include some on board geometric corrections for aircraft motion (e.g. HEIS-McDonald Dettwiller). Frame cameras, such as the example shown on Figure 6 are less susceptible to aircraft motion, since data acquisitions for an entire frame just happen once within a frame.

In detail, the geometry of the imageries shows a distortion due to a misalignment of pixels between two successive lines. These shifts between lines are due to the difference in synchronism in the analog to digital recording process. The discussion about imagery's resolution constitutes part of the next paragraph.

4.2 - IMAGERY RADIOMETRY

Thought it is still premature to consider the radiometric characteristics of the sensor, there are two radiometric related phenomena which were observed in the imagery and will be discussed here. Although both phenomena are target-related, one has more to do with sensor performance itself.
It was previously mentioned that the nominal ground resolution of the sensor was predicted in 76cm. However, target as small as 30 cm can be observed while targets as big as 120 cm cannot be discriminated. In both cases this has to do with target-sensor characteristics. In the first case, high performance, it can be noticed from Figure 7 that, for instance, marks in the soccer field small as 30 cm wide, which are greener and taller than the surrounding grasses, once vegetation shows strong absorption in the red portion of the spectrum, the results are a radiometrically high contrasted area which in turn, were easily detected by the sensor. The second case, low performance, will be in apparent paradox with the example given above, since highly contrasted areas formed by black and white plastic strips, located up to 120 cm apart, were not detected by the sensor. This leads to two other observations, both regarding imagery forming process: one concerning along track imagery formation and the other concerning across track imagery formation. Along track, that is between two successive lines of an imagery, the strongly bright response due to the white strips in the ground may have overwhelmed the dark response of the black strips, thus yielding mixed pixels with a radiometric response dominated by the adjacent, bright targets and as a result of this it degraded the imagery’s resolution (see also Welch, 1971; Monro, 1979). Although the phenomenon above can be mainly related to the target’s characteristics, data taken with other sensor during the same test flight (aerial photographs) show clearly the alternated pattern of black and white strips of the three-bar-target (Figure 7).

In addition to the mixing pixel features there is another radiometric aspect in the across track direction, that is within the same line of an imagery, which may have also compromised the resolution of the sensor. Barker (1984) during studies of radiometric calibration of E-M scanners, noticed that when the TM and MSS sensors of the Landsats were scanning out over highly contrasted areas a memory effect was produced in the detectors - what he called bright target effect. This effect consists of a radiometric inertia (Fusco and Grevsen, 1984) of the detector after being exposed to bright contrasted areas (e.g. clouds versus sea). In terms of imagery, the bright target effect results in a coherent noise (detector’s memorization) which propagates from the point where the detector became saturated through several subsequent pixels. Now, in terms of self-scanning devices such as INPE’s pushbroom camera, a similar phenomenon was observed in these imageries which included bright targets, or specular reflection targets. In the imageries, bright targets tend to show smeared edges which reduce their sharpness and, consequently, the imagery’s resolution. Differently from E-M scanner, this radiometric effect may be related to cross-talk between detectors or blooming, where the charges detected in one well of the CCD (i.e. one pixel) are transferred to adjacent wells (i.e. adjacent pixels) and, as a result, the imagery shows targets with unsharpened edges. Notice that in CCD scanner type of devices the noise propagation can be symmetrical, that is to any adjacent pixels, compared to E-M scanner where the noise propagation due to a bright target is asymmetrical, that is only to the subsequent pixels.

5. CONCLUSIONS

The intentions in a preliminary test flight of a sensor are not necessarily to present a neat product to the end user, but rather to observed the functional performance of the sensor and as corollary of this, to analyse its products. Thus, to continually improve the performance of a sensor, one has to look for its major drawbacks. Naturally, one adequate way to do this is to analyse the results, i.e. the imageries. This is what this paper tried to show: INPE’s first experience with pushbroom sensor imageries.

As mentioned in this paper, pushbroom type of sensor will permit INPE to explore the advantages of linear array architecture such as high radiometric sensitivity, high resolution imageries.

Preliminary imageries have shown satisfactory quality. Despite imagery distortions due to aircraft attitude, most of urban area features are readily identifiable and radiometrical and spectral separability were attained. Therefore,
allowing for aircraft motion compensation and for electronic and recording techniques, the next experiments will permit to obtain an improvement on imagery quality.

6. BIBLIOGRAPHY


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FIGURE 1 - SCHEMATIC REPRESENTATION OF IMAGING DEVICES - A - E-M SCANNING DEVICE, B - SELF-SCANNING DEVICE ("PUSHBROOM"), C - FRAME DEVICE.
FIGURE 2 - PUSHBROOM SENSOR ARCHITECTURE.  
In a pushbroom or self-scanning type of sensor every ground resolution element is sensed by a corresponding detector.

FIGURE 3 - SCHEMATIC REPRESENTATION OF IMAGERY GEOMETRY
The right side of the figure shows a schematic representation of a three-bar-target which was laid down in the ground during the test flight. The left side of the figure shows an enhanced portion of the pushbroom imagery. Imagery enhancement was obtained through a computer's printer.
FIGURE 5 - STREET PATTERN AS SEEN BY THE LINE IMAGING CAMERA (SEE TEXT FOR DISCUSSION).

FIGURE 6 - STREET PATTERN AS SEEN BY A FRAME CAMERA (AERIAL PHOTOGRAPH, SEE TEXT).
FIGURE 7 - INPE'S MAIN CAMPUS AREA

(A) Line imaging camera. (B) Frame camera (aerial photograph).
TBT = three-bar-target.