Smart Optical Processor for Imaging Spectrometry

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❒ Résumé

Pour obtenir de bonnes images avec une caméra haute définition à balayage en peigne, l'orientation de la plate-forme du satellite lors de la prise de vues doit être connue avec précision. Les erreurs de l'image dues aux incertitudes du pointage peuvent être corrigées au sol d'après les informations d'attitude associées à chaque ligne de balayage ou encore, ainsi qu'on a pu le montrer, d'après les informations de position par rapport au sol au moment de la prise de vues. Un corrélateur optique permet de retrouver ces informations sur les images successives prises avec le télescope couplé à l'instrument.

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❒ Introduction

High resolution pushbroom imaging instruments and spectrometer have several advantages over staring imaging systems with large area sensors. These include lower cost, small field of view (FOV) in one direction and the ease with which multi-spectral capability is obtained. Linear image sensors can be arranged to form a long linear array, to cover the complete FOV of the objective lens of a telescope. However pushbroom scanning systems are extremely sensitive to attitude instability which introduce geometrical distortion into the scanned image (Figure 1, left). This inherent weakness prevents the use of simple pushbroom imagers on platforms which have only moderate attitude stability, typical of low-cost, small satellites.

The distorted images can be corrected after acquisition using recorded measurements of the relative pointing position on-ground at the time the image was acquired. This record can be obtained from optical correlation of successive images, taken with the imaging telescope of the pushbroom instrument. In this way, the movement of the satellite pointing vector during the acquisition of two subsequent image lines can be determined.

Conventional systems derive appropriate measurements of attitude from auxiliary sensors onboard the satellite, such as inertial sensors (gyroscopes). However when combined with a high resolution camera, this approach has three main disadvantages:

- it requires high performance gyroscopes;
- it is expensive and takes up valuable onboard resources like power and mass;
- it introduces systematic measurement errors (e.g. mechanical deformations) when the gyros and camera have different mountings.

❒ Solution

The proposed solution relaxes the requirements on the attitude stability of the platform and is more accurate and cost effective compared to inertial measurements using gyroscopes. The correlation process is performed by a robust optical correlator, which guarantees a high calculation rate, a compact structure, small mass and low electrical power demand and which tolerates mechanical loads.

The system employs two small auxiliary matrix image sensors in the focal plane of the telescope alongside the pushbroom line sensor (Figure 1). These auxiliary matrix sensors produce sequences of mutually overlapping images at defined time intervals. The overlapping images are used to determine the image motion vectors and the amount of distortion introduced into the scanned image on a line-by-line basis.

The required image data processing rate is high and beyond the capability of an onboard digital processor. To meet the requirements on high accuracy and fast operation, an optical joint transform correlator has been developed for computing the two-dimensional Fourier transform. This device is robust and tolerant of optical system misalignments and mechanical deformations and it has the potential to achieve the high reliabilty needed for autonomous space

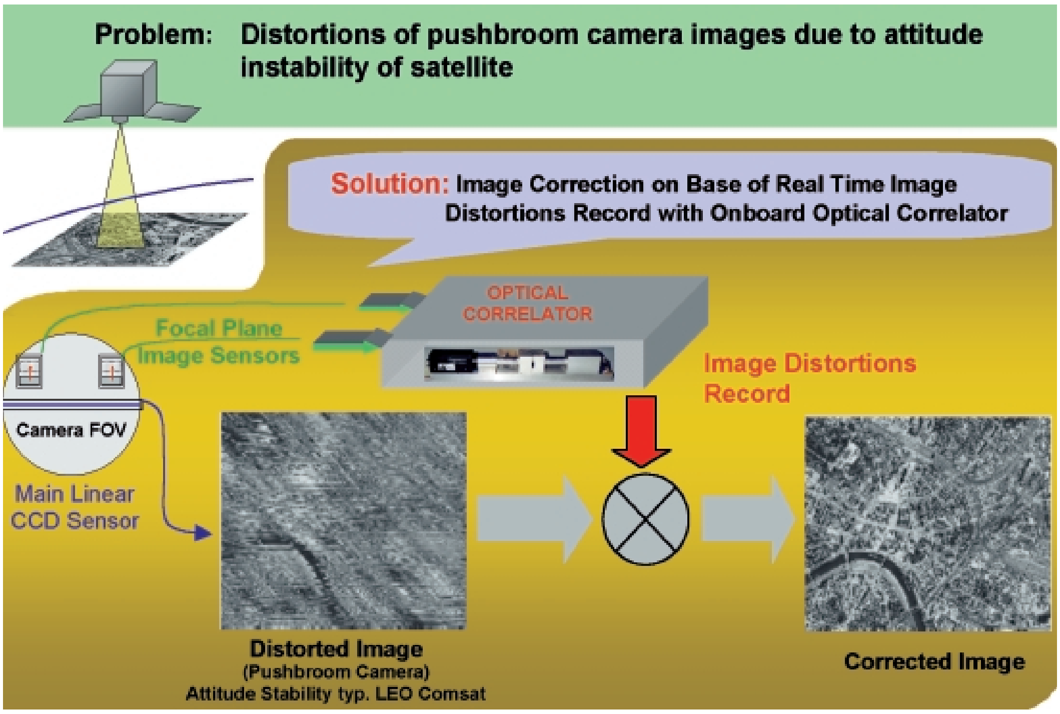

Figure 1.
General description of the use of optical correlation for correcting image distortion (see text).

applications, through the uses of redundancy. The scanned image data, together with the record of the measured distortions, are transmitted to ground. Using special correction software, the distorted image is corrected a posteriori and delivered to users.

The solution can be easily integrated into the existing infrastructure of a remote image acquisition system. The required changes to onboard equipment are limited to a small redesign of an existing pushbroom camera, and the installation of the optical correlator processor. The impact to the ground system is limited to the inclusion of the correction processes in existing image pre-processing software.

❐ Optical correlation techniques

A joint transform optical correlator is an optoelectronic device, which computes the cross correlation between two images. It employs a lens to take the two-dimensional Fourier transform of an image. The principles of optical correlation were developed in the 1960s. Due to the latest achievements in opto-electronic technology, the size, mass and power consumption of this device have been significantly reduced and they are now promising candidates for spaceborne systems. An optical correlator can process image data ten times faster than a digital fourier processors and can withstand harsh mechanical environments.

❐ Advantages of the new design

The advantages of using an optical correlator for image corrections are:

— high measurent accuracy;
— image correction to sub-pixel accuracy;
— accuracy is independent of camera resolution and orbit parameters;
— no residual errors due to the use of separate mountings for the attitude measurement sensor and the camera.

This system can be applied to high resolution telescopes onboard spacecraft to improve the accuracy of attitude and vibration measurements.

❐ Applications

Possible areas of application include (but are not limited to) the following:

— small and low-cost imaging payloads for existing and planned low Earth-orbit communication satellites;
— low-cost imaging missions with moderately stabilised platforms such as small satellites, aircraft or high altitude balloons;
— small imaging payloads for planetary imaging missions.

❐ Conclusion

The concept of using an optical correlator to provide pushbroom imaging on moderately stabilised platforms in space has been was proven by constructing a laboratory model of the optical correlator and writing approriate image simulation software. This image acquisition technique allows strict requirements on the attitude stability of a satellite to be relaxed and it makes possible the introduction of new low-cost imaging missions.