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Implementing an image processing system for the next generation Earth observation sensors for the SUNSAT 2 micro-satellite programme

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Abstract

The next generation of microsatellite Earth observation sensors will generate more data than can be downloaded in real-time by a ground-station. Managing the data volume is thus crucial to the regular access to data (operational success) of these missions. For the Sunsat 2 programme a combination of image processing and lossy image compression will be used. This paper will give an overview of the considerations and solutions for next generation microsatellite imagers.

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1. Introduction

The next generation of Earth observation sensors for the Sunsat 2 programme will generate more data than can be downloaded in real-time by a ground-station. Due to the limited download bandwidth and the limited contact time between the low Earth orbit satellite and the ground-station network, it becomes important to reduce the data by some means.

Two alternatives for data reduction are investigated: The first is to perform data processing and information extraction onboard the satellite and then only transmit the results. The second is to perform lossy data compression on the raw data and

transmit the compressed result. Many compression options are possible, with wavelet-based lossy image compression algorithms presently being preferred.

This paper will explore the viability of the two image processing options and the hardware implementation options.

2. The SUNSAT 2 multi-sensor imager data requirements

The data requirements considered for SUNSAT 2 include more than 3 multi-spectral bands between 6000 and 12000 pixels each, a panchromatic sensor and a hyper-spectral sensor with up to 200 channels.

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3. The data processing solution

By doing all the processing onboard the satellite, it is possible to obtain significant levels of data reduction. This section looks into the processing required to extract the necessary information from the images.

3.1. System corrections

Image compression schemes attempt to only transmit a number of bits representing the true information in the scene, and are able to compress low information areas because there is little detail present. Instrument defects producing high spatial information should thus be removed prior to compression to avoid keeping the compression busy encoding instrument defects.

Both area and linear sensors have fixed pattern noise. One component of the noise is independent of the illumination level of the pixel, and is related to dark current differences and other offsets between pixels. A second component is proportional to signal level (PRNU—photo-response non-uniformity) and results from variation in the photo-response of pixels arising from small geometric differences from masks, lithography, and etching.

The first image correction is thus a pixel offset. The offset correction should also remove any clock feed through artefacts from the data.

On area arrays, it is possible to develop line dropouts due to failure of one of the transfer cells. To avoid the effects of such a line being spread further by a compression algorithm, the line should be replaced by the nearest valid line prior to compression.

To avoid transmitting large cloud-covered areas, the final function to perform on-board the satellite is to delete large cloud-covered areas before passing data to the downlink encoders.

3.2. Atmospheric corrections

The atmosphere and particles contained in the atmosphere, reflects, refracts and absorbs electromagnetic waves. These effects are not uniform and vary as temperature, pressure, particle distribution and ground-level changes. Effective correction of these effects requires a detailed model of the atmosphere and some knowledge of the atmospheric condition at the time of image acquisition.

Some good models do exist (like the 6S-model), but to obtain the best results, the input data to the model needs to be very accurate. This may require a high level of human control. Also, the algorithm does require significant processor time, and is best implemented on the ground.

3.3. Geometric correction and referencing

Geometric correction removes the effects of optic viewing geometry, satellite orientation, land slope and shadows in images while geometric referencing is the process of mapping the pixels of an image to actual earth coordinates. The level of processing that is appropriate depends greatly on the purpose of the imagery.

Geo-referencing is done by identifying ground control points (GCPs) in the images, and warping the image to match the known location of the points. By identifying enough GCPs, polynomial equations can be generated that will transform the image. The image is then resampled in the new coordinate system.

3.4. Extracting the required information

After all appropriate corrections above had been completed, the information extraction process can start. Some processes, such as looking for unauthorized fishing activities is potentially implementable on-board, but most information extraction is best performed on the ground where human interpretation is feasible.

Another issue to consider is the specific application. Different applications will require different sets of information and since the objective is to effect data reduction, this solution is only viable in missions where a defined set of information needs to be generated and transmitted to the ground station.

3.5. Conclusion

The amount of human interpretation necessary to obtain good information results, means that most processing will remain to be done on the ground, and the main purpose of on-board processing is to prepare data for efficient compression and downlinking.

4. The Lossy image compression solution

Lossy image compression offers significantly higher compression ratios than lossless compression algorithms. The algorithms cannot guarantee the perfect reconstruction of the original data, and many maximize the human visual appeal by exploiting known insensitivities of the human visual system. Care must be exercised that the radiometric information (or scientific data) in the images is not corrupted as a consequence of the processing.

In addition to adversely affecting the useful information contained in the images, lossy compression may also make some image corrections and classifications, described in the previous section, more difficult to perform successfully on the ground.

Although an initial implementation of Shapiro's Embedded Zerotree Wavelet (EZW) image compression algorithm [1] has shown attractive results, the Sunsat 2 programme presently prefers a guaranteed maximum distortion level, which is not possible with the original EZW algorithm.

5. A compromise solution

Both previous solutions have some shortcomings. By combining the two solutions, some of these shortcomings can be avoided. The idea is to perform some parts of the image processing chain on-board the satellite before using the lossy compression to compress the resulting image. However, this will require an understanding of how each step in the processing chain will affect the science data in order to better judge which steps to place onboard the satellite.

5.1. The impact of Lossy wavelet compression on the science quality of images

5.1.1. Mapper

The mapper transforms input image to new domain to reduce inter-pixel redundancies using the wavelet transform. The image is transformed into a joint time–frequency domain (Fig. 1).

Impact on data quality: loose high-frequency components.

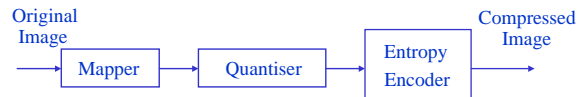


Fig. 1. Wavelet compression processing chain.

5.1.2. Quantiser

The quantiser reduces psycho-visual redundancies using Shapiro's Embedded Zerotree Wavelet Algorithm (for this investigation). The quantiser progressively encodes most important information.

Impact on data quality: loose small contributions to absolute values.

5.1.3. Entropy codes

The entropy encoder reduces coding redundancies in a lossless mechanism.

Impact on data quality: none.

5.2. Impact of the general processing chain on the science quality of images

The two steps of the image processing chain that can have the greatest impact on the science quality of data are the system corrections and the atmospheric corrections. Both of these phases remove artefacts from the image and it is this removal of the artefacts that improves the science quality.

Due to the reasons outlined in Section 3, the atmospheric corrections will not be considered for implementation onboard the satellite at this time. Therefore, only the system corrections are done on-board.

The EZW algorithm used in evaluation tests is not very good at dealing with noise in the images. Noise added into the satellite image before compression could not be extracted as thoroughly from uncompressed images, even when it could be readily removed from the original images.

5.3. Alternative error functions for Lossy compression algorithms

The compression algorithm needs an error function to tell it when to end the compression process. Usually, this error function will monitor the current compression rate and stop as soon as a preset minimum ratio has been reached.

By replacing this error function with one that can monitor the quality of the data the compression process can be stopped when a certain level of quality is reached.

6. Hardware implementation options

The Sunsat 2 programme requires a platform with reconfigurable hardware and software to allow for in-mission upgradeability of the image processing system. Furthermore, to meet the real-time requirement, it must be a high-performance platform.

Three implementation options have been identified: The first is to use a single, very fast processor that will run all the necessary algorithms. However, the only processors capable of achieving the real-time goal are the higher end desktop pc-type processors. These processors require a large amount of power, which is dissipated as heat, and thus these processors are not suited for microsatellite use.

The second solution is to use soft-core processors in FPGAs in conjunction with dedicated hardware also running in FPGAs. This option was explored and it was found that the soft-core processors are not fast enough to meet the real-time requirement.

The third solution is to use a higher performance microprocessor (for example microprocessor from the MIPS32-class) in conjunction with dedicated hardware in FPGAs. This will give a good balance between high performance and reconfigurability and may be able to meet the strict real-time requirements.

7. Conclusion

Future camera payloads produce data volumes (and -rates) far exceeding downlink capability, making it essential to compress data on-board the satellite. Care has to be exercised in the processing to remove artefacts at the correct processing step and also to ensure that while maintaining good visual appearances of imagery, the radiometric values are not allowed to drift—an effect to which the eye is not sensitive.

References

- [1] J.M. Shapiro, Embedded image coding using Zerotrees of wavelet coefficients, *IEEE Trans. Signal Process.* 41 (12) (1993) 3445–3462.