IMAGE PROCESSING AND NAVIGATION FOR THE METEOSAT PROJECT

M. Jones and K. G. Lenhart
European Space Operations Centre
Robert-Bosch-Strasse 5
D-6100 DARMSTADT (Germany)

1. Introduction

An operational system for the precision preprocessing and navigation of METEOSAT images is described. The main features of the system are that it performs the following essential functions:

- image data acquisition
- preprocessing, including such functions as inter-channel registration, line phase correction and fine gain adjustment
- navigation, involving the production of accurate image deformation models; these deformation models in effect permit transformation between image coordinates (pixel, line) and geographical coordinates (latitude and longitude), with a target accuracy of 1 IR pixel r.m.s. or better.

The image processing and navigation system forms part of a large centralised data processing system dedicated to support of the METEOSAT satellite.
Thus the user can be provided with high quality preprocessed image data and its associated navigation data; the burden of preprocessing and navigation is removed from individual users, who would otherwise need substantial facilities both in terms of hardware and software.

This paper will deal mainly with that part of the METEOSAT ground processing system dedicated to image processing/preprocessing. For a general introduction to the whole system, including discussions of the satellite, radiometer, the ground system and the various missions, the reader is referred to ref. 1.

2. Spacecraft and Radiometer

METEOSAT is a geostationary, spin-stabilised spacecraft. It rotates at 100 r.p.m. and scans spin-synchronously. A normal image scan takes 25 minutes and has 2500 lines. One of the main tasks is round-the-clock provision of weather images.

The radiometer images in three spectral bands namely infra-red (IR) 10.5-12.5 μm; visible (VIS) 0.4-1.1 μm and the water-vapour absorption band (WV) 5.7-7.1 μm. There are two visible sensors whose size, position and sampling is such that the visible resolution is twice that of the IR and WV. The pixel sizes at the subsatellite point are 5 km (IR) and 2.5 km (VIS).

3. Ground Processing Hardware

The image acquisition and preprocessing discussed in §4 is performed on a dedicated minicomputer (SIEMENS 330) with an array processor attached to handle the CPU intensive operations. This combination of hardware is known as the Front-End Processor (FEP); the processing performed on the FEP is subject to severe real-time constraints since it has to handle each line (10 Kbytes of raw image data) in 600 ms. The FEP passes each line to a large general-purpose mainframe (ICL 2980). The mainframe writes each preprocessed line to disc files thus building up complete images.

As concerns image processing, the mainframe is also used to:

- (i) provide support functions for the preprocessing (e.g. preparation of fine gain adjustment factors, deconvolution kernels)
- (ii) support all geometric processing (navigation)
- (iii) support eventual archiving of all image and image-related data.

In order to assist image navigation, landmark consoles are attached to the mainframe via a NOVA 830 computer. Image data is transferred from the filestore of the ICL 2980 to the disc storage of the NOVA 830 or the refresh store of the display.

4. Image Acquisition and Amplitude Processing

4.1 Functional Steps

The images are acquired line-by-line, each line being sent from the ground station to the processing centre at ESOC Darmstadt over a high-speed link.
Image acquisition consists of decommutation of the raw image data to give separate lines of data for each spectral channel. This also involves expansion of the 6 bit visible and WV pixels to 8 bits (the IR image has 8 bit pixels).

Amplitude preprocessing involves the following functional steps:

(i) registration of the various channels so that the same navigation formulae can be applied to all channels

(ii) horizontal (one-dimensional) deconvolution of all channels to compensate for the transfer function of the sampling electronics

(iii) vertical (two-dimensional) deconvolution of the IR-channel to take account of the optical effects resulting from the detector size

(iv) phase correction of the line start on all channels so that the earth's disc appears in the centre of each image. This function involves as a first step computation of the times of the first sample of each line, based upon various counter values given in auxiliary data in the image stream and in the spacecraft housekeeping data. This timing data is used in subsequent deformation modelling (see §5) as well as in real-time phase correction.

(v) fine gain adjustment of the image by a linear stretching in order to compensate for changes in radiometer response.

All the above functions are performed in real-time on the front-end processor.

4.2 Support Functions for Amplitude Processing

In order to carry out the amplitude processing described in the preceding subsection, certain support functions are necessary. To make the system as flexible as possible the various parameters (e.g. registration parameters, deconvolution kernels, gain factors for on-ground gain adjustment) are sent to the preprocessor as a single parameter block before each image commences.

Whereas the registration parameters and deconvolution kernels normally remain fixed, the following data needs updating regularly:

(i) the various geometric data used in the phase correction process (principally, Earth-satellite -sun angles)

(ii) the on-ground gains used for fine adjustment of radiometer response.

For the IR channel, the on-ground gains are adjusted frequently (generally once or twice daily) based upon black-body calibrations. These calibrations involve viewing an internal 'black-body' of known temperature through part of the radiometer optics; the measured gray-level value together with the radiance of the black -body as computed from the known temperature of the black-body give a direct measure of the radiometer response. The on-ground gains can thus be computed as an inverse function of the measured radiometer response. The on-board gains can also be adjusted, but only in rather large steps. This serves to provide a coarse adjustment of the channel dynamic ranges; fine adjustment being made by ground software.

5. Geometric Processing and Navigation

5.1 General

The purpose of the geometric processing is to locate the image pixels in terms of earth coordinates. This is necessary because

- the satellite's orbit is not fixed in position with respect to the earth, although it is in a geostationary orbit;
- the attitude of the satellite does not point exactly along the normal to the orbital plane and it drifts with time;
- the process of scanning results in changes in the moments of inertia of the whole system which results in motion of the spin axis during the scan;
- there are various fixed misalignments between the radiometer axis and the satellite spin axis;
- the line start is not ideal, due to e.g. quantisation effects in the line-start electronics, finite width of the reference pulse (normally detection of the sun's

disc);
- the satellite spin-speed will normally differ from nominal; it will also vary slightly with scan step.

For these reasons, the actual images differ from the reference image, the reference image being defined as that obtained when the satellite is (a) at its reference station, (b) has attitude parallel to the Earth's polar axis, (c) rotates at a speed of 100 r.p.m. exactly and when (d) the horizontal and vertical pixel sampling rates are uniform and independent of scan step or pixel number.
The deviation of the real image from the reference image is known as the deformation; this quantity is calculated for each image from a physical model which takes into account the known orbit of the satellite, the attitude and other spacecraft dynamical characteristics.

5.2 The Dynamical Model

The dynamical model gives the direction of the radiometer optical axis in an earth-centred reference frame as a function of time.

The model is parametrised in terms of the attitude and of angles describing the other physical effects mentioned above. In effect, the model gives the direction of the optical axis as a function of time and the various adjustable angular parameters.

The dynamical model is used to compute the relationship between the scan step and geographical position for a set of sampled points in the image. Two cases can be distinguished:
- restitution, in which measured pixel scan times are substituted into the model;
- prediction, in which pixel scan times are predicted, normally for one or two slots ahead.

A sampled field of distortions can thus be computed. This field of distortion vectors can be fitted to polynomials in the image coordinates. Fifth order polynomials have been chosen since they are capable of representing the distortion over the whole image with sufficient accuracy.

5.3 Updating the Dynamical Model

The model is updated by input of measurements made upon

the image namely:
- horizon (earth-edge) detection
- landmark extraction.

The horizon detection task runs automatically and provides the addresses of the earth-edge intersections in each image line.

The landmark extraction task is interactive: the operator can display an image, or sections of an image, on a screen and can align these real data with a reference landmark template (in the form of a line graph) which is superimposed on the real data. A set of such measurements distributed over the entire disc can be made. These measurements together with the earth-edge measurements can be substituted into a set of observation equations, solution of which gives refined parameters for the deformation. This model is used to predict deformation polynomials and matrices (sampled deformations on a uniform raster), applicable to images up to two slots (one hour) ahead of the image being currently acquired. The polynomials and matrices allow the user to transform locations in the real image into geographical coordinates (direct transformation) or to find out which pixels on the real image correspond to fixed geographical locations (inverse transformations).

In practice, two principal strategies are used in updating the deformation models, namely:
(1) determination of the attitude parameters of the model by analysis of horizon data spread over a whole day;
(2) rather more frequent updating of other parameters of the model using horizon and landmark data together with precise timing data.

Separation into two strategies in this way has the advantage that the system may run using strategy (1) only; this provides an acceptable model in a completely automatic way. For refined accuracy (1 IR pixel or better) the strategy (2), involving operator interaction, must also be employed.

5.4 Maintenance of Raw Image Geometric Quality

As mentioned earlier, the deformation modelling process provides a fine determination of the attitude. This fine attitude is then used in the computation of the lowest radiometer scan step and the parameters controlling the line start. These parameters are sent to the satellite as telecommands before each image. The scan thresholds compensate for the diurnal variation in the elevation of the spin-axis above the orbital plane. Thus even in the raw image there is near-optimal centering of the earth's disc within the image frame (the centering accuracy is generally better than ± 5 IR pixels absolute and relative centering accuracy between neighbouring raw images is normally better than ± 1 IR pixel).

6. Image Products

Image products are available in three basic forms, namely:

- image data disseminated via METEOSAT
- image data archived on digital magnetic tapes or as photographic negatives
- image unit files, also on magnetic tape, providing sophisticated windowing facilities for particular chosen image areas.

6.1 Disseminated Image Data

Disseminated image data is relayed to the user community via the spacecraft. Two forms of transmission are used, namely WEFAX analogue transmissions and digital (high-resolution) transmissions. The former are compatible with the transmissions from other meteorological satellites, whereas the latter are specific to METEOSAT and give the user processed data together with all essential interpretation data (e.g. deformation models, absolute calibration coefficients). Image data is disseminated in near real-time i.e. within about half-an-hour of image reception. Images from all METEOSAT spectral channels are included in the dissemination schedule which includes formats (or image pieces) covering the entire METEOSAT field of view at least once every three hours.

6.2 Image Archiving

The archiving subsystem provides for the archiving of all image and image-related data in digital and, where appropriate, in photographic form. The storage medium of the digital archive consists of high-density digital tapes (HDTs). Digital retrievals are made by copying from the archive on to either computer-compatible tapes (CCTs) or HDTs.

The photographic archive is maintained on negative film produced by a VIZIR laser beam recorder. Retrievals are in the form of contact prints of the original negative film or specific enlargements of particular areas ('windows') in the original.

6.3 Image Unit Files (IUFs)

Image unit files are image areas, each of which consists of 256 lines of 256 pixels (i.e. 64 Kbytes). The image areas can be either full resolution or can be sampled at a lower rate. The position of the image unit in the image and the sampling rates (vertical and horizontal) are at the discretion of the user requesting a unit or sequence of units. Options exist to either (a) geographically recentre each unit (so that its centre pixel always corresponds to the same latitude and longitude as the corresponding pixel in the reference image), or (b) completely rectify each area. In the latter case, the process of rectification consists in resampling the image with the help of the deformation model so that it matches the reference image.

7. Image Quality Control

The general philosophy of quality control is to evaluate a set of quality indicators for each image received and to store these parameters for about two weeks. The quality parameters of each image received in that period can thus be dumped; operations staff can then see the evolution of the various quality parameters and can quickly detect any degradation of the system due to malfunction of any part of the image chain.
Typical examples of quality parameters computed for each image are (1) number of lines lost due to ground system problems, (2) channel-dynamic ranges and S/N ratios, (3) residual distortion after application of the deformation model to the preprocessed image.
An interactive real-time display image facility also exists and has proved indispensible for radiometer commissioning and general image quality inspection.

References

(1) Introduction to the METEOSAT System
(J. Morgan, Issue 2, December 1978: ESA/ESTEC Reproduction Services)