NEAR REAL TIME CCD ARRAY HEALTH CHARACTERIZATION OF CAMERAS ONBOARD IRS

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ABSTRACT:

Satellite captures and then transmits remotely sensed image to the earth station, which is further sent to the processing station. At processing station, it undergoes various types of geometric/radiometric corrections. The generated product has to qualify certain quality ascertaining tests, before reaching to the user. This paper discusses an expert system, which works as a quality check at data reception itself. The applied algorithm uses threshold-based rules to evaluate the absolute and relative behaviour of the even/odd ports of the Charge Coupled Devices (CCDs) used in satellite camera. The rule-thresholds are learned from the laboratory measured calibration data. Stringent conditions are simulated with the rules and thresholds for the histograms, so that any deviation from the rules of the package can be identified. This work was initiated with the Indian Remote Sensing mission Resourcesat-1, later incorporated for Cartosat-1 and Cartosat-2. It is successfully giving un-interrupted support as a quick-quality feedback (within one hour of data acquisition). The package is integrated in data-processing chain at the Earth Station and has a fully automatic approach of analysis.

1. INTRODUCTION

Every earth resource on each and every part of the globe is in human knowledge today, only due to the space-borne remote sensing. All this started with the key concept of solid-state radiation detection. In this concept, photons are directed on silicon-based detector (photo-diode, CCD (Barbe 1975), CID, CMOS), which converts it into electronic current. This technology offered features like true space point (pixel-based information), high dynamic range, low power dissipation, little or no geometric distortion, sampled signal output and rapid response time. Space-borne CCD detector technology was introduced by MSU-E (Multispectral scanning unit- electronic) flown on Meteor-Priroda-5 (launched June 18, 1980(Earth Observations, web)) spacecraft of the former Soviet Union. Then, came the era of commercial imagery, started with the launch of SPOT-1 of France in February 1986, using the solid-state devices – CCDs. Closely following, Indian Space Research Organization (ISRO) has flown a number of satellites from the launch of Indian Remote Sensing satellite (IRS) IRS-1A in 1988, which are capable of giving coarse to very high-resolution images in different spectral channels. Linear array of discrete detectors, CCDs are being used in IRS space-borne opto-electronic telescopes. IRS Satellite systems use push broom technique to collect the data, utilizing the satellite motion. It has multispectral high-resolution imager like LISS (Linear imaging self scanning), AWiFS (Advanced wide field sensor), and OCM (Ocean color monitor) for the remote sensing applications in the field of agriculture, ecology, geology, oceanography, atmosphere etc. It has PAN (pan-chromatic) camera with very high-resolution capability of 1 m for the cartographic purposes.

These CCD arrays can be designed in three ways. First way, using a simple CCD shift register clocked in such a way that the shift-out time is very much less than the integration time. Second way, by using separate sensors and shielded readout register and the third design uses a line of sensors and two shielded readout registers. In this, odd-numbered pixels are shifted into one readout register and even-numbered pixels are shifted into the other readout register. The third design has primary advantages of higher sensor packing density and fewer transfers to read out a given pixel (Barbe 1975). This design, even/odd detectors of CCD arrays connected to different ports electronically, is used in IRS missions.

Received satellite data is transmitted to the earth station and then sent to the processing station. At processing station, it undergoes various types of geometric and radiometric corrections, taking care of earth's rotation, satellite motion, detector's response etc. There exists a data quality evaluation (DQE) system. It has independent way of judging the geometric and radiometric quality of the satellite images. The generated product has to qualify these quality-ascertaining tests at different stages, before reaching to the user. The first phase of the quality-check starts at the time of the data reception itself, so that an alarm about any kind of anomaly can be generated in advance to the processing of the data to generate the end product. This paper discusses an expert system, which works in the near real time. The system analyzes port-wise image histograms (generated according to the CCD architecture). On

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the basis of this quick feedback, some corrective action can be initiated.

The objective of this paper is to discuss the expert system, which establishes the detector array performance (detector array characterization (Palsule et al. Aug2002; NRSA, web; Palsule et al. 2008)) from scene histogram analysis. In second section, detailed methodology is described and discussed, which will cover the algorithm details, giving examples with real Resourcesat-1, Cartosat-1 and Cartosat-2 data. In the third section, the details of the expert system are given. This section comprises of the parameter definition and the rules. And at the end, section four has some simulated results, speaking the potentiality of the system.

2. METHODOLOGY

A typical CCD port architecture (Payload team 2005) can be visualized from the figure 1.

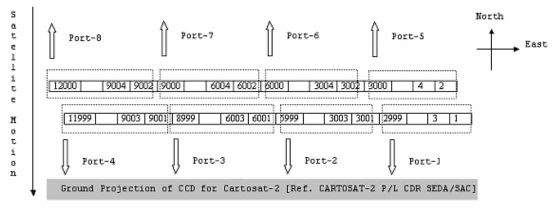

Figure 1 (Typical CCD architecture)

Above figure (a 12000 detector array is shown) depicts that even and odd detectors are electronically connected to different ports. While imaging, even and odd ports would be looking at the same terrain (almost). There is very less probability of very drastic pixel-by-pixel spatial variation of ground.

The histogram is an approximation of the discrete probability density function of a random variable whose realization is the particular set of pixel values found in the image. An Image histogram has a computational advantage (Tutorials, web) of being a uni-dimensional function (while an image is a bi-dimensional function of brightness). And the information contained in this (though little less than image) is significant and can be well utilized to tackle the kind of problem taken up here. This analysis procedure seeks its base in the laboratory calibration and in the LED based on-board calibrations. Even/odd histograms should be ideally same as they are looking at the same terrain, except the intrinsic difference due to the manufacturing of the CCD. This intrinsic difference is allowed with the help of thresholds. And if the difference exceeds, it clearly indicates anomaly. Following figure 2 (Srivastava et al. 2004) shows the overlaid histograms of set of lines of even and odd ports of the above-mentioned typical CCD architecture.

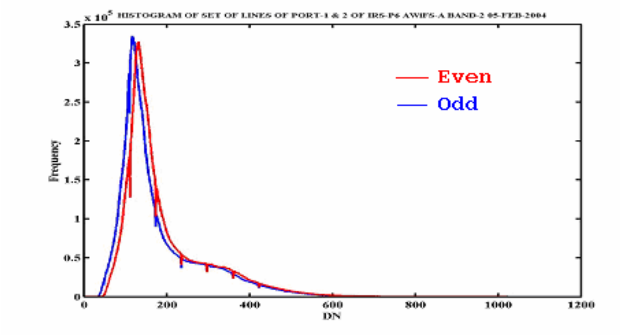

Figure 2 (Histogram of set of lines for even and odd ports of the CCD)

The histograms clearly have the similar trend. It puts the foundation for our thought for this algorithm/package. Ideally even and corresponding odd port should have a similar histogram, though we may allow some offset in terms of digital number (DN) and frequency, we call it thresholds here. Figure 2 is taken from Wide Field of View sensor of Resourcesat-1.

The provision for in-flight calibration of CCDs using Light Emitting Diode (LED) exists for all IRS missions. This provision is exercised during calibration mode at night pass within visibility of ground station. This mode is planned once in 24 days cycle time. The LED based calibration system characterizes detector health without optical system. In this scheme, illuminating LED's with changing exposure time generates predefined constant calibration levels. Every IRS mission has onboard calibration facility with variable exposures. In this scheme, the CCDs are continuously illuminated by LEDs located near CCDs (excluding optics) covering total area of the CCDs (uniformly). CCD performance is evaluated with different stochastic parameters (our analysis takes input from even/odd detector-port relative response). The detector response is linear for increasing exposure-intensity. A typical graph (figure-3) showing even/odd response (for the different CCDs of different payloads) follows:

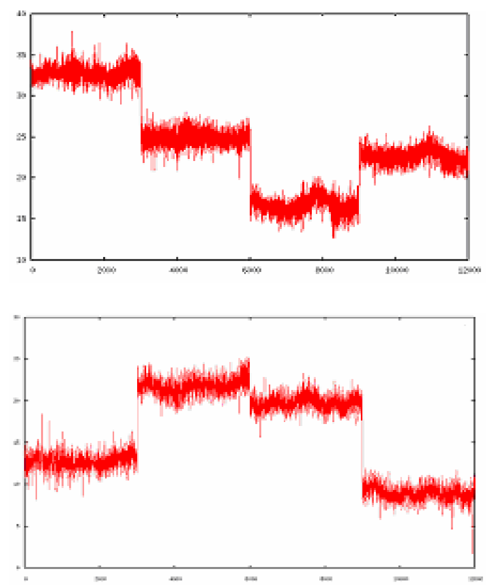

Figure-3 (Even-odd relative counts difference CCD-1 and 2 for a particular luminance at 20°C)

In above figure, fixed difference between even and odd port of the CCDs (Refer CCD-architecture in figure 1) is observed. Following table 1 shows typical even/odd port response difference, which is seen consistent (up to first decimal) for one intensity level at the operating temperature of 20°C. Payloads are mostly operated in the temperature range of 18-24°C.

Port Id	P1/P5	P2/P6	P3/P7	P4/P8
Count difference (laboratory)	34.75	26.61	14.19	21.08
Threshold	40	30	20	25

Table 1 (From the DQE analysis of laboratory measured thermo-vacuum data (Pandya et al. 2005; DQE team 2005))

The typical thresholds shown in the table 1 are fixed with the help of calibration data and exercise with the initial phase histogram analysis along with the corresponding scene data. Similarly, every rule of the expert system has a different set of thresholds. The expert-system rules are discussed in the following section. These thresholds are modified every month (if required), with the help of detailed radiometric analysis of the data.

Coming back to histogram generation, it is done for all the ports according to CCD architecture. A number of random samples (≈20) are collected for the entire pass and expert system takes decision on the basis of the consistent behaviour throughout all the samples. Histograms are limited to the random order, in which samples are taken, as it may miss some time-dependent phenomena. What may appear to be the central tendency of the data may be deceiving. But, even with these limitations, histogram analysis has appeared as an invaluable tool in the elementary stages of the data analysis (Rahn et al., web).

Expert system applies rules one by one on all port-histograms, and writes the inference in a report. This report consists of parameters, applied thresholds, generated flags and simple inference remarks about the histograms being analyzed. After checking all ports, expert system also generates one executive summary report, which reflects the performance of the overall system. If any abnormality is found about the port-behaviour in the executive summary then details are probed to find the exact cause. The approach is fully automatic in nature. The system is a part of the data reception chain itself. As soon as the data is archived, system evokes and completes the analysis within near real time.

The methodology applied here is fully independent of the type of the terrain (homogeneous/heterogeneous), level of quantization, spectral resolution, spatial resolution, type of environmental conditions, and mode of acquisition. Hence, it is applicable to variety of CCD-payloads irrespective of their other characteristics.

3. EXPERT SYSTEM DESCRIPTION

Even/odd port histograms are separately probed for the absolute port behaviour and then relative behaviour is judged. Parameterization, parameter calculations and rules are discussed in the following sections.

3.1 Parameterization

Histogram is a representation of frequency of occurrence of an event, in this case the event is gray count recorded by sensor at given time. The complete histogram is characterized by following parameters. Following six parameters are computed from the histogram, their definition and significance are tabulated in table – 2.

Parameter Name	Definition	Significance
Cmin	The first minimum count observed with the corresponding predefined frequency limit, which is a fixed percentage of the total pixel population.	Difference of maximum and minimum count represents range of counts depicting dynamic range of reflected energy recorded by sensor. The spread of gray count under histogram indicates heterogeneity of terrain.
CminCF	Frequency corresponding to the Cmin count.	
Cmax	The maximum count observed with the corresponding predefined frequency limit, which is a fixed percentage of the total pixel population.	
CmaxCF	Frequency corresponding to the Cmax count.	
Fmax	Maximum frequency	Indicates peak of histogram (in most of the cases), and hence the maximum occurring count in the lines selected for the histogram generation.
FmaxCC	Corresponding count to Fmax	

Table 2 (Six Significant Parameters of Histogram)

Cut off frequency criteria is used (0.01% of the total pixels selected for the histogram generation), instead of taking first non-zero value from both ends of the histogram. It ensures the Cmin/Cmax to be of the major distribution of the histogram.

All parameters are computed by skipping the small peaks in the histogram (which may be due to a low reflecting small target or some kind of noise), as the analysis compares the major peak of the even/odd histograms. In case, we do not skip these minor peaks, it may lead to the wrong finding of the histogram parameters. Following figure 4 (real example of LISS-3 of

Resourcesat-1) tells the importance of skipping of peaks and its impact on the histogram parameter. We would have picked the Cmin-1 instead of Cmin-2.

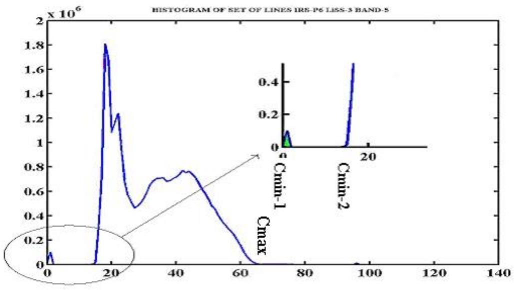

Figure 4 (Skipping of the spurious peak)

All parameters indicated above are applicable to staggered pixels, even-odd ports. This difference in parameter performance of detector array configuration is monitored using thresholds. The basic rules are generated in methodology to check similar or dissimilar behaviour of each parameter. The rules are applied in sequential manner, so that exact problem can be pinpointed. Following section explains the rules in detail.

3.2 Rules

3.2.1 Quantization Verification: Gray Counts are verified for the quantization limit (e.g. for 7 bits data, quantization limit = 127). It is done for all the ports.

3.2.2 Absolute port behaviour estimation: Histogram of each port is separately checked. First, total population is computed, and then the corresponding frequencies of each count are checked. If corresponding frequency of any of the count equals the total population, it reflects anomaly in the histogram of the port, showing artificial trend. As histogram is expected to have a certain distribution, it is unlikely to have the same count from every pixel in the lines selected for the histogram generation.

3.2.3 Inter-port relative port behaviour estimation: Even/Odd ports are checked for their relative behavior. As histogram of the even/odd ports should have nearly similar picture (already discussed above), within the thresholds, which is due to the intrinsic difference in the CCD detectors. The difference in both count and frequency is compared with the thresholds here.

1. The difference of Cmin/Cmax of even and corresponding odd port should not exceed the thresholds for the allowable count-difference, as observed in the laboratory (+15-20% tolerance added for avoiding the false alarming (Refer Table 1 and 2). In case of higher count difference, a remark would be added in the summary report for the ports for further analysis.
2. Even if the differences of Cmin/Cmax of even and corresponding odd ports are within thresholds, qualifying part (1) of this rule, the difference of corresponding frequencies of Cmin/Cmax should not exceed the 20% of the total population (fixed with the help of exercise carried out over plenty of scene data). In case of higher frequency difference, a remark would be added in the summary report for the ports asking for further analysis.

Here, a point to be emphasized is, even and odd ports must not have identical pattern, which is purely artificial. It is also checked.

3.2.4 Check whole Data: After computing parameters for all the histogram sets available for the entire pass, Cmin/Cmax and their corresponding frequencies and their differences are checked. If same trend of observations throughout the pass exists, then detail analysis is carried out of the scene data for the entire pass.

4. RESULTS

There was no deviation found till date, for the missions Resourcesat-1, Cartosat-1 and Cartosat-2. These satellites fulfilled all mission-objectives. But, to show the potentiality of this package, we simulated some conditions in the histograms using the actual data of these payloads. We deliberately introduced the erroneous conditions. The first case (figure 5) is simulated for the absolute port behavior. In this case, histogram does not have a bell shape distribution at all, which is not a normal condition. All the pixels in the selected area for the histogram generation are reflecting the same energy, which is an extremely idealized condition for the detectors as well as for a homogeneous ground. The second case (figure 6) is of idealized detectors response condition and artificial even/odd ground trace pattern, where the histograms of both even and odd ports are absolutely same (both histograms are kept on the single axis, laterally sifted for visualization). The cases for the ill relative port behaviour follow. Figure 7 shows the case for the count-difference perfectly within the threshold limits (real case), and the simulated case (figure 8), shows the lateral shift in the histogram. It exceeds the allowed limit through thresholds. It depicts that the ground trace of the even and odd pixels cannot have great difference in the reflectance throughout the image, or they are somewhat correlated. After that, figure 9 represents a case, where even and odd histograms are matching in the expected way. If there is some anomaly in the port behaviour and few of the detectors start giving inappropriate response to the photon stimuli, means either they generate more current for the less electrons (showing charge not flushed out in the last read) or less current for the more photons (may be due to the substrate malfunctioning). The histograms of the even and odd ports may differ in the way of figure 10, which is again an unexpected condition.

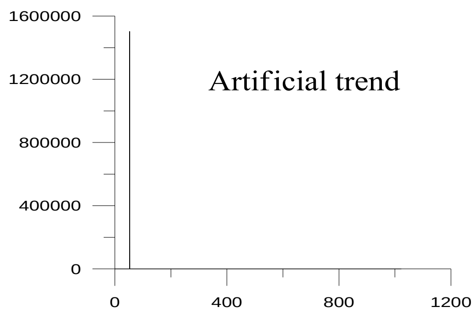

Figure 5 (Abnormal condition for the histogram)

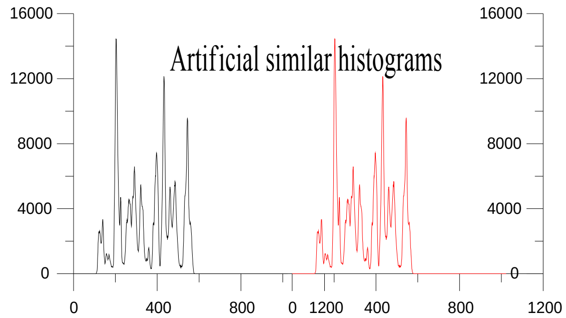

Figure 6 (Identical histograms of even/odd ports – anomaly)

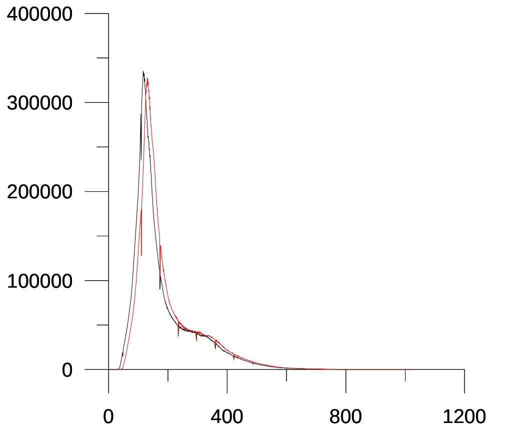

Figure 7 (Ideal histograms of even/odd ports – real case)

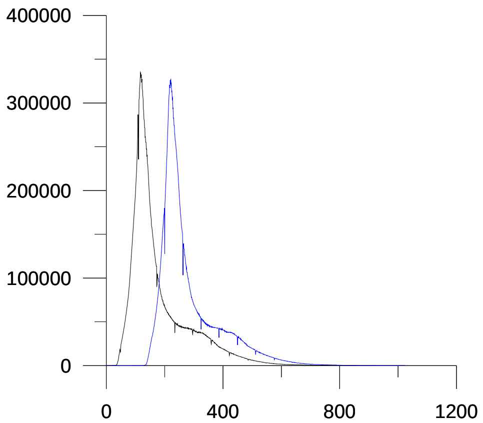

Figure 8 (Histograms of even/odd ports with high difference in Cmin and Cmax parameters)

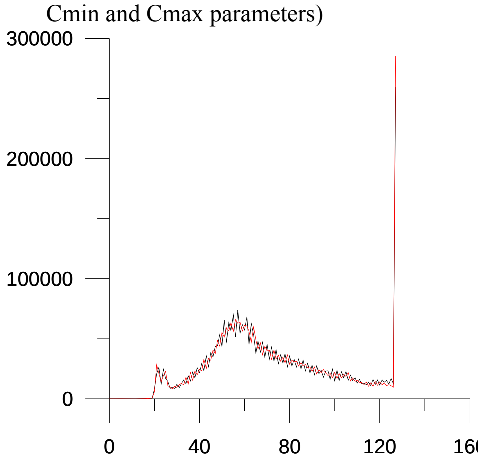

Figure 9 (Expected trend of histogram of even/odd ports – real case)

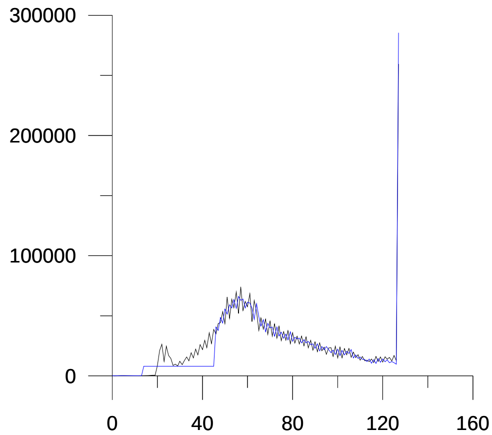

Figure 10 (Histogram of even/odd ports with high difference in the corresponding frequencies of Cmin and Cmax parameters)

A typical executive result table (Table – 3) from the expert system for all the above-simulated cases follow. It is a port-wise histogram analysis report, containing status and observations.

Collateral Information about the satellite pass Satellite Name / Date of Pass / Orbit Number			
Sr. No.	Port Identification E- even O- odd	Status	Remark
1	Port-E (Ref. Figure-5)	Anomaly Observed	Artificial trend
2	Port-E & Port-O (Ref. Figure-6)	Anomaly Observed	Identical histograms
3	Port-E & Port-O (Ref. Figure-7)	Ports OK	-
4	Port-E & Port-O (Ref. Figure-8)	Anomaly Observed	High difference in Cmin & Cmax
5	Port-E & Port-O (Ref. Figure-9)	Ports OK	-
6	Port-E & Port-O (Ref. Figure-10)	Anomaly Observed	High difference in corresponding frequencies of the Cmin & Cmax

Table -3 (Typical executive summary report – of the simulated cases discussed above)

5. CONCLUSIONS

This study presented a method, which acts as a quick quality-feedback in near real time. It is a trade-off between time and accurate monitoring of the quality. It has really helped mission to check if there is any problem in transmission of the data, it has also shared the workload of the radiometric analysis package by giving an indication about the quality of the product in advance. The results generated by the package are kept in continuous observation through database (DQED team 2004; DQED team 2005). The algorithm is independent of the type of the terrain (homogeneous/heterogeneous), level of quantization, spectral resolution, spatial resolution, type of environmental conditions, and mode of acquisition. Also, there are possibilities of the new problems, which may be further seen or speculated, and then can be introduced in the rules. Hence, it is an evolving tool.

A study is in progress to work on the correlation between this activity and the main radiometric quality evaluation, so that detailed radiometric analysis can be performed on the selected products (instead of all products), signalled by this package.

REFERENCE:

Barbe, David F., Member IEEE, "Imaging devices using charge coupled devices", Proceedings of the IEEE, vol. 63, No. 1, pp. 38-67, Jan. 1975.

Palsule, S.S., Bankim Shah, G. Paswan, Anuja Sharma, Anjali Garg, Hetal Pandya, Shailendra S Srivastava, Sampa Roy "RESOURCESAT-1 DATA QUALITY EVALUATION SYSTEM", paper submitted/accepted in International Journal of Applied Earth Observations and Geo-Information (JAG).

DQED team, "Detail Design Review Document for IRS-P5 DQE software system", Internal document number IRS-P5/DQE/SAC/RESIPA/SIPG/DQED/TN-01/Apr 2004

DQED team "Design Review Document for CARTO-2 DQE software system" internal document number SAC/RESIPA/SIPG/DQED/CARTOSAT-2/TN-22/October 2005

Pandya, Hetal, Anjali Garg, S.S.Palsule, "Onboard calibration data analysis of Cartosat-2 PAN camera", SAC internal note number SAC/RESIPA/SIPG/DQED/Cartosat-2/TN-23/November, 2005.

Payload team, "Critical Design Review document on Cartosat-2 payload" Internal document Number SAC-SEDA-IRS-10-07-05

Srivastava, S.S., Sampa Roy, S.S.Palsule, "Port-Wise histogram analysis of the IRS-P6 Sensors (Analysis and Up-gradation), SAC internal technical note number IRS-P6/DQE/SAC/RESIPA/SIPG/DQED/TN-14 /AUG'04.

Earth Observation Satellites catalogue on http://directory.eoportal.org/pres_Meteor1Meteor2MeteorPrirodaSeries.html

Rahn, N., M. Price, K. Raines, R. Reddy, D. Robinson, http://deming.eng.clemson.edu/pub/tutorials/qctools/histm.htm

National Remote Sensing Agency (NRSA) of Indian Space Research Organization (ISRO) of India website http://www.nrsa.gov.in/IRS_Documents/Handbook

Tutorials at http://www.cee.hw.ac.uk/hipr/

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