Integrating Expert System Module with the Image Processing Module for Real-Time Generation of Satellite Images

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ABSTRACT
This work aims to generate ready to use image products in real-time by acquiring the data directly from weather satellites. As part of pre-processing, detection and correction of defects in the image data also needs to be carried out in real-time. To facilitate this, an Expert System has been devised. In order to construct images in real time, innovative techniques of real-time image representation have been developed. These two modules are expected to run in coordination with each other. This paper presents a novel approach for integrating the Expert System module with the Image Processing Module.

General Terms
Satellite Image Processing, Automated System.

Keywords
Expert System, Image Representation, Look-up-table, VHRR, Reasoning, Dynamic Database, Palette encoding.

1. INTRODUCTION
By definition "the weather forecast is a statement describing the future state of the atmosphere over a given area during a specified period or instant of time from the initial known state of atmosphere"[1]. The process of weather prediction is subjective with the starting point being the knowledge of the initial state of atmosphere. To be able to describe the initial state of atmosphere meteorologist needs instrumental meteorological observations such as a satellite image. In order to confirm the correctness of prediction and to refine the future prediction, updates of current state at frequent intervals is essential. The accuracy of prediction depends largely on the correctness of the initial state refined with sufficient iterations as well as the time span between the time of definition of initial condition and the time for which the weather is predicted.

The advent of satellite-based observations, over the past two decades, has added new dimensions to the study of atmosphere and weather systems. The dynamic nature of weather systems could be captured through the time series of synoptic observations in the form of images by the satellite borne instruments. This makes the satellite image as an indispensable source of information for weather prediction.

Meteorological image data from the imaging satellite is acquired and archived as per the operational imaging schedule. Processing of this data is conventionally taken up by the human experts as offline activity as per the application requirements. In order to carry out these tasks, typically two kinds of systems are employed namely the Data Reception (DR) System and the Data Processing (DP) System [2, 3].

The Data Reception System is interfaced with the data acquisition hardware and it is responsible for the scheduled reception of image data from the satellites and further archiving of this data into the mass storage devices like NAS (Network Attached Storage) or SAN (Storage Area Networks) systems. The stored data becomes the input for the Data Processing System, in which the preprocessing tasks like removal of noise, correction of sensor offsets, and removal of sampling errors as well as generation of final images are carried out.

In this type of traditional processing scheme, the Data Processing system works on the offline data and image products are generated as part of offline activity. The conventional processing task calls for intervention of experts at various stages of processing. The final images are available for the end user after a time delay which is equal to the image acquisition time plus the processing time.

Specialized weather prediction like aviation and aerospace weather forecasting requirements demand earliest update from the imaging instrument. Internal to ISRO, weather is also one of the deciding factor for pre-launch and launch activities. An update on the current weather condition in the form of processed image, just before launch plays a vital role.

This research work was taken up to evolve new techniques and algorithms to facilitate generation of real-time, ready to use imageries. The Met-Payloads Data Processing System (MPDPS) at Master Control Facility (MCF), Hassan has been under constant enhancement to facilitate generation of the processed imageries in real-time [4]. These imageries are expected to contain the processed information and at the same time they need to be generated on the fly so that they are immediately available for use by the meteorologists at the launch facility. The functionalities of conventional Data Reception and Data Processing systems have been merged into this single system.

In order to automate the preprocessing of the real-time image data both in a way and at a level comparable to that of human experts, an Expert System [5] has been designed. Various reasoning methods [6] of artificial intelligence have been employed to detect the defects in the real-time image data, which will go as inputs to the image processing module for correction.

In order to enable generation of image products on the fly, the Look-up-table based palette encoding technique [7] has been developed as real-time image representation method. This ensures construction of ready to use images as and when the data is being acquired.

The Expert-System and the Image-Processing modules are integrated using a novel concept of Dynamic Database. The implementation details of realized system in general and the concept of dynamic database in particular are discussed here.

2. INSAT IMAGING INSTRUMENT

INSAT imaging instrument [8, 9] called as VHRR (Very High Resolution Radiometer) has been designed to image the earth in three spectral bands namely VIS-Visible, TIR-Thermal Infrared and WVP-Water Vapour. It has a basic telescope and scanning mechanism for scanning the earth disk. The scanning mechanism employs a scan mirror mounted on a two-axis gimballed mechanism, and capable of rotating (about limited angles) in two orthogonal directions. During the imaging operation, it facilitates to generate a two dimensional image by sweeping the IFOV (Instantaneous Field of View) of the detectors across the earth's surface in East-West (called Fast Scan) and North-South (called Slow Scan) directions. Imaging is carried out in both west to east and east to west directions in fast scan. At the end of each scan line, the mirror is positioned down by an angle equivalent to 1 IFOV of TIR (0.01280) and imaging continues. The major specifications of the instrument are given in the table 1.

Table 1. Specifications of INSAT VHRR

1	Spectral Bands	Visible (VIS) 0.55 – 0.75 μ meters
		Thermal Infrared (TIR) 10.5 – 12.5 μ meters
		Water Vapor (WVP) 5.7 – 7.1 μ meters
2	Number of Detectors	4 main & 4 redundant for VIS
		1 main & 1 redundant each for TIR and WVP
3	Spatial Resolution	2x2 for VIS (Combining all four)
		8x8 for TIR & WVP
4	Instantaneous Field of View (IFOV)	56 μ rad (0.0032^0) for VIS
		224 μ rad (0.0128^0) for TIR & WVP

VHRR has the following three modes of operation, depending on the extent of earth coverage requirement in North South direction.

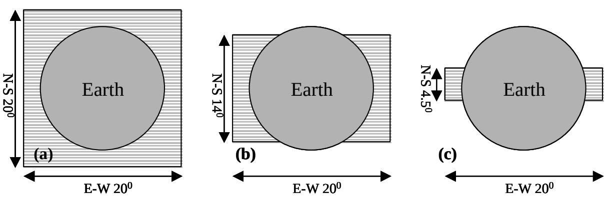

Fig 1: Image area covered by VHRR in (a) Full mode scan, (b) Normal mode scan and (c) Sector mode scan

1. Full Mode: 20^0 (North-South) x 20^0 (East-West) covers the entire earth disc & some space around, scanning 1560 lines in about 33 minutes.

2. Normal Mode: Covers 14^0 (North-South) x 20^0 (East-West), scanning 1092 lines in about 23 minutes

3. Sector Mode: A sector of 4.5^0 (North-South) x 20^0 (East-West) selectable from 32 predefined sectors positioned in steps of 0.5^0 in North-South direction. 351 scan lines cover a sector in about 7 minutes. During sector mode of imaging, a sector is repeatedly scanned thrice by default, unless stopped by the ground command.

3. EXPERT SYSTEM MODULE

The defects in the image received from the spacecraft depend mainly on the deficiency in the performance of the onboard imaging instrument. The performance and the current configuration of the instruments are revealed through the house keeping parameters derived from telemetry, which typically updates once in every second. These parameters include analog data such as the scan mirror positions, servo errors, servo currents and temperature of various onboard components; as well as discrete status readings such as scanning direction, scan progress status etc

The expert system has been designed to be a set of intelligent computer programs that are capable of detecting the defects in real-time from the acquired telemetry data. This system consists of three modules namely, the Reasoning Module, Knowledge base and the Actions Module.

In order to embed the intelligence of detection of the defects into the Expert System, various reasoning methods have been explored. The studies of similar systems developed earlier [10, 11] for space borne instruments indicate variant implementation of rule based reasoning method. In order to meet the design goals it was found that no single method could completely fulfill the requirements and therefore the following reasoning methods are adapted in our approach.

- Rule Based Reasoning
- Case Based Reasoning
- Model Based Reasoning

We have used Rule based reasoning systems with "if-then" conditions to represent the domain knowledge Rules are framed based on certain conditions, which are derived by the combination of status and analog parameters. The preconditions, or "if", part of a rule are checked against a set of facts as revealed by the acquired data. If the facts found to satisfy the preconditions of a rule, then the "then" part of the rule is executed. The "then" part, once executed could perform some action or it could trigger another rule.

In the Case based reasoning the trends of selected parameters are verified with respect to their nominal trend. Deviation in the trends would indicate anomaly in the imaging instrument.

Detection of some of the image defects was required to be modeled. Specific parameters are derived by computation of data under the model to get the derived parameters. These derived parameters are used as the indicators of the defect.

The Knowledgebase consists of satellite specific fact data as well as the rules defined by the domain experts. It hosts limits database, trend database, rules database and model parameters.

For every update of telemetry, the reasoning system looks for rule violations, trend deviations and computation of derived parameters followed by their verifications if any.

Upon the trigger from Reasoning Module, the defects are logged into disk files and communicated to the image processing module as explained in the next section. In addition, audio alarm in the form of pre-recorded human voice is also announced for critical anomalies.

4. IMAGE PROCESSING MODULE

For generation of real-time image products we considered the Indian sub continental region spread approximately from 60^0E to 105^0E longitude in east-west direction and 5^0S to 40^0N in north-south direction. This portion of the image forms the sub set of VHRR Scan in Full mode and Normal mode as shown in the Fig. 2(a) and Fig. 2(b).

Though the spatial resolution of the visible band is 2km x 2km (combining all the outputs of the four visible detectors), only sub sampled image of 8km x 8km is taken to keep the resolutions of all spectral bands identical. Considering these facts the image size has been worked out to be 600 pixels x 650 pixels for each spectral band.

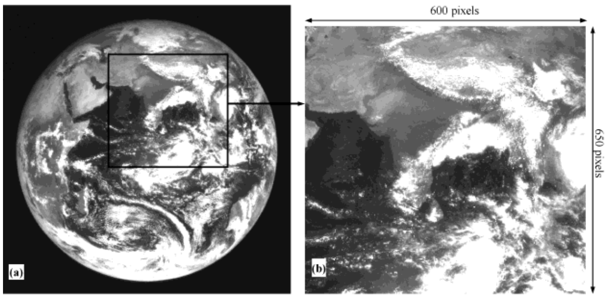

Fig 2: (a) Full mode VHRR image, (b) subset image considered for auto generation.

Conventional images in each spectral band, namely Visible, Thermal Infrared and Water Vapor are generated by mapping the corresponding digital counts to image pixel gray values through defined mapping functions. False colour composite image is generated by mapping the Visible digital counts to both red and green channels and Thermal Infrared digital counts to blue channel.

In an approach to generate ready-to-use, processed image, the processed information like the cloud top temperature, sea surface temperature from Thermal Infrared and humidity information from Water Vapor channels has been embedded into single image to form an Enhanced IR image.

The Thermal Infrared digital counts represent the spectral radiations corresponding to the temperature of the target being scanned by the imaging instrument. One needs to apply Plank’s law of radiation for conversion of these digital counts into corresponding temperatures after calibration.

The planks equation for radiation involves the exponential (inverted logarithmic) components, which are computationally intensive, especially for a computer program that needs to compute for every pixel of the image portion as received from the satellites.

To overcome this difficulty, a look-up-table to relate every possible value of image digital counts in thermal infra red band to a value of brightness temperature is generated off the hands during the calibration process.

In an approach to indicate the temperature ranges of the features, colors from the predefined palette are used. The total dynamic range of Thermal Infrared channel has been organized into convenient temperature ranges. The color palette is created by assigning shades of selected colors to these temperature ranges. The temperature value for every pixel in the image is obtained using corresponding TIR digital count as an index to the look-up-table.

In order to encode the abundance of water vapor, two humidity thresholds from the WVP channel have been identified. These two thresholds are marked on the EIR image as + and # symbols.

5. INTEGRATION SCHEME

The Expert System module and the Image Processing Modules have to work coherently and concurrently in an integrated system. In order to achieve this, a novel concept of “Dynamic Database” has been thought of.

The concept of Dynamic Database has been devised such that it works as a channel of communication from the Expert System module to the Image Processing Module. The dynamic database resides in the memory and holds the stock of defects detected by the Expert System, which is refreshed for every update of acquired image data. Depending on the number of the defects detected for current update of the image data, the size of this database also varies.

The image-processing module refers to this database through the interpreter module that translates the defects into the correction vectors. Using the correction vectors the image processing module corrects the data and the image corresponding to the current update is constructed on the fly.

Figure 3 shows the architecture of the currently operational system, in which the expert system module has been integrated with the image processing module.

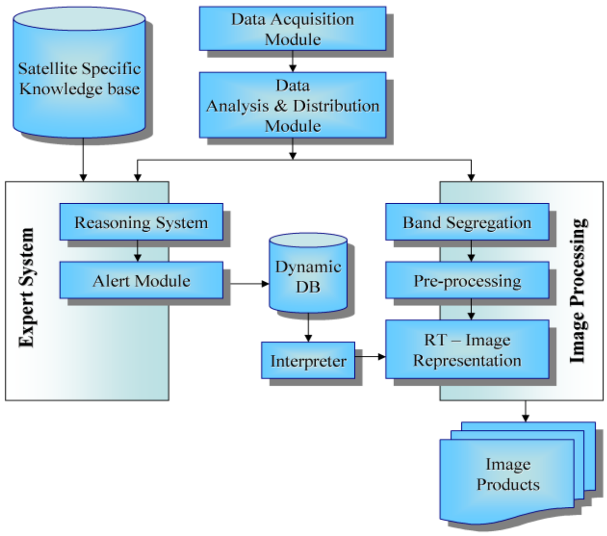

Fig 3: Architecture of the Integrated System.

Following are the advantages of this concept of dynamic database.

- It is flexible so that its contents can vary dynamically depending on the defects found in the current update of image data acquired from the satellite.
- It ensures necessary isolation and freedom to both Expert System Module and the Image Processing Module for independent modification and inclusion of their processing schemes or algorithms.

- It is well suited for multi-threaded parallel processing schemes, which is essential for this kind of real-time image generation tasks.

6. IMPLEMENTATION

Both of these modules (Expert System and Image Processing modules) have been implemented as part of Met Payload Data Processing System (MPDPS).

The operational requirement of the system compelled the design of the Telemetry Module to be flexible such that the system could be configured for operation either on the server workstation where the real-time telemetry is acquired from the acquisition hardware or on a client computer in which case the real-time telemetry is received from the server over the TCP/IP network. This enables execution of the Expert System either at the payload data processing facility or at the satellite control center which are geographically apart. In addition Telemetry Module in off-line mode can read the pre-recorded telemetry frames from the specified disk file and play them in time sequence. This feature is essentially used for test and investigation on the old data. The raw telemetry frames (either acquired in real-time or read from the disk file) are pre-processed for deriving all the payload parameters using the parameter definition and interpretation tables and then distributed to other modules including the Expert System and the Image Processing modules..

For every update of telemetry the three reasoning modules compute parameters and evaluate them for any rule violations or trend deviations. The trigger index is set for the found anomalies. Upon the trigger from Reasoning Module, the actions module updates the Dynamic Database and also provides audio alarm for severe defects.

In the concurrent Image Processing Module, the data collection thread is ready with the band segregated data for the required area of coverage for all bands. The products generation thread refers to the Dynamic Database through the interpreter to get the error vectors to be considered for correction. The following inferences are made from the error vectors.

- Whether the data in each band is declared usable or not.
- Image shift in E-W direction : Magnitude in terms of number of pixels and the direction of correction (towards right side or left side)
- Image shift in N-S direction : Magnitude in terms of number of lines and the direction of correction (upwards or downwards)

The preprocessing module effects these corrections. If any spectral band data is declared not usable, the corresponding image product will not be generated.

7. RESULTS

The integrated system discussed above has been operational for KALPANA (originally named METSAT) VHRR. Currently VHRR scans are taken in normal mode for every 30 minutes, thus generating 48 images per day. The integrated system generates the 5 image products (Visible, Thermal Infrared, Water Vapor, False Color Composite and Enhanced IR) for each of these scans.

Though the normal mode of VHRR scan requires 23 minutes to complete, the required Indian sub continental region is covered in first 15 minutes. The image products are also generated immediately; facilitating meteorologists to access these processed images 7 minutes prior to scan completion.

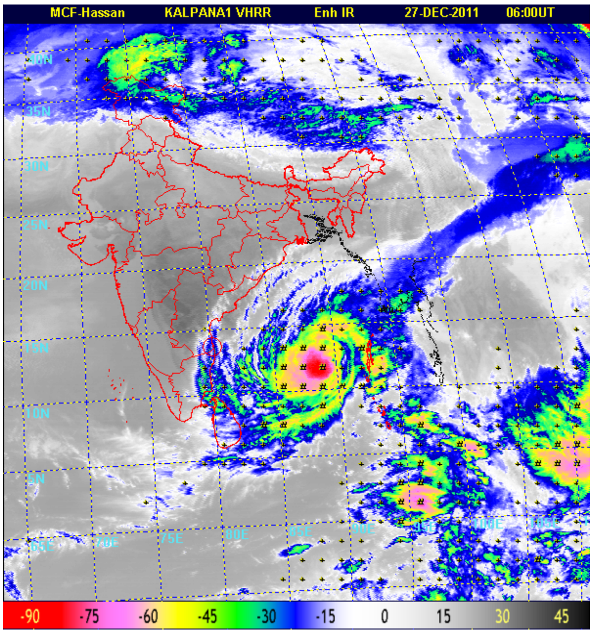

Fig 4: Defective offset in the image; map superimposition improper. Image generated while the Expert system module was intentionally disabled.

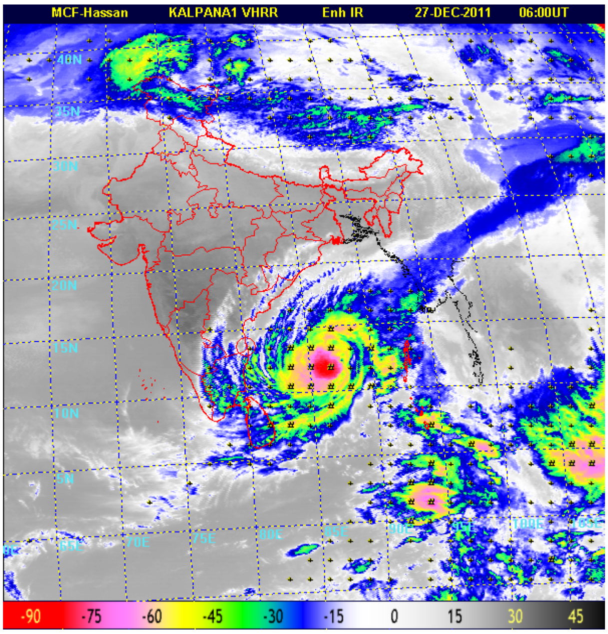

Fig 5: Enhanced IR Image generated by the integrated system. The offset is detected and corrected.

Due to bad space weather, the onboard counters for scan mirror positions get corrupted resulting in the shifts of image in either east-west or north-south or both directions [12]. Fig.4 shows the defective offset in the image, which caused wrong superimposition of the map and latitude-longitude grid while the expert system module was intentionally disabled and the corresponding data is replayed the image in offline mode. Figure 5 shows the image generated by the integrated system, where the shift in the image is detected by the Expert System module and the same has been corrected by the Image Processing Module, Indian map and the latitude-longitude grids are properly superimposed.

8. CONCLUSION

The integrated system has demonstrated the usefulness of integrating the Expert System module with the Image Processing module. The concept of dynamic database has been tested to be ideal for this kind of real-time dynamic data exchange. Ever since its implementation, the image products are being generated automatically avoiding frequent intervention from the human experts.

9. ACKNOWLEDGMENTS

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