CHAPTER 3

NEW SCHEME FOR WEATHER FORECASTING USING COLOUR COMPUTING ALGORITHM

3.1 INTRODUCTION

The chapter-2 discussed the new scheme for satellite RAW data preprocessing and image representation. The defect detection, correction and image representation are also discussed. This chapter deals with the Colour Computing Algorithm (CCA) for weather forecasting. Earth observation satellites carrying imaging payloads transfer images to the ground station in real-time mode. Geostationary satellites provide imageries in various spectral bands of meteorological importance, with a synoptic coverage on a periodic, repetitive basis.

3.2 BACKGROUND

The recent advances in satellite technology in terms of high resolution, multi-spectral bands covering visible, infrared and microwave regions space data an inevitable component in weather monitoring and dynamic modeling are involved. The image representation plays a very important role in highlighting the embedded features of the image which is easily interpreted by the user. Traditionally the image data from the satellite imaging instruments are acquired and archived as per the operational imaging schedule.

The preprocessing, information retrieval and reconstruction of processed image are carried out by the human experts. Data acquisition software receives the satellite data over the visibility region of the ground station. After image data acquisition, the time frame by which the processed imageries are to be made available depends on the varied requirements of weather forecast. The time frame
could be a few hours for weekly/daily forecasts or a few minutes for nowcasting requirement like aviation meteorology and aerospace meteorology where near real-time information is essential for taking right decision in available short time. INSAT series and METSAT (KALPANA-1) satellites have provided the most consistent operational services to the nation for more than three decades. The METSAT satellite was launched by ISRO on September 12, 2002 and operates till today. METSAT (renamed as KALPANA-1 on February 5, 2003 after the Indian-born American Astronaut Dr. Kalpana Chawla, who died on February 1, 2003 in the US Space Shuttle Columbia disaster) is the first in the series of exclusive meteorological satellites built by ISRO. INSAT spacecrafts with meteorological payloads being operated at geostationary orbit provides a stable platform to monitor and study the generation and growth of cyclones, i.e. cyclogenesis, weather forecasting systems and to measure the meteorological parameters.

3.3 WEATHER FORECASTING SYSTEM

The weather observing techniques have become increasingly complex in recent years and satellites have now made it possible to monitor the weather globally. Weather forecasters are then made with help of computers and super computers. Weather information and forecasts are of vital importance to many activities like agriculture, aviation, shipping, fisheries, tourism, defence, industrial projects, water management and disaster mitigation. The persistence forecast is good for only a very short time, usually six hours or less. Meteorological forecasts are made from various rules and equations using computers as well as the experience of forecasters to develop an improved forecast that may be for six hours or as much as five days in the future. The climatological forecast is based on upper air patterns, cycles, statistics, or sunspots and is used to give variations in the weather over an extended period of time.

The weather satellites provide imageries in various spectral bands of meteorological importance, with a synoptic coverage on a periodic, repetitive basis. The periodic image updates are ideally suited to study weather-related, dynamic atmospheric process on different scale.
The Colour Computing Algorithm includes all types of image processing, including optical image production, sensing, digitalization, electronic protection, encoding, processing and transmission over communication channels.

3.4 COLOUR COMPUTING ALGORITHM FOR WEATHER FORECASTING

The data used in the proposed scheme is taken from VHRR payload raw data, which is obtained by normal mode scan. The data collection platform decides to start performing preprocessing procedure according to the scan line numbers. The process includes the removal of oversampling, servo errors and geometric corrections. After segregation of the video data, the data are collected into three separate buffers which are identified for each of the spectral bands. The collected data are also processed for oversampling and servo errors. Product generation thread is signalled after collection of the data from the last required scan line. The steps performed in colour computing along with preprocessing are illustrated in the Figure 3.1.

The following four products are generated in BMP format.

- Visible image (VIS)
- Thermal Infrared Image (TIR)
- Water Vapour Image (WVP)
- Enhanced IR Image (EIR) (Colour computed IR Image)

The first three image products are generated by mapping the corresponding video counts to image pixel grey values through a defined mapping function. The mapping functions for all the bands are static and no dynamic contrast/brightness enhancement is considered. This enables the comparison of the corresponding features from the images taken at different times.

In the proposed scheme, TIR image product representation is only considered because the IR images show good contrast between clouds at different levels, not achievable in VIS imagery. The most important advantages of IR imagery is that it is available at any time but VIS imagery is available only in daylight hours.
Figure 3.2 illustrates the VIS and corresponding TIR images of a typical day. Figure 3.2 (d, h) shows VIS and TIR of 21:45 UT i.e. 3:15 A.M (IST). The difference in the solar illumination over Indian region in these images taken at different times of the day is readily evident in these images. Here the TIR image represented in the Figure 3.2 (h) is very clear cloud contrast and thus the importance of TIR images can be understood very well. Each and every TIR image (including night images) is important during uninterrupted cyclone tracking.
Figure 3.2 VIS and corresponding TIR images of a day (1<sup>st</sup> Oct 2013) a), e) 00:15 UT, b), f) 07:15 UT, c), g) 12:15 UT and d), h) 21:45 UT

In a TIR band the hot regions are indicated by dark features and cooler regions are indicated by whiter features. For meteorological application the precise temperature range of features is very important one, for example sea surface temperature or the cloud top temperatures.

In the proposed method the indication of temperature ranges of the features, different colour gradation are computed to different temperature ranges by using a lookup table to get an Enhanced Infrared image. VHRR radiometer is an instrument designed to measure the intensity of the incoming radiation, the Thermal Infrared detector outputs onboard meteorological payload correspond to the thermal energy, i.e. the temperature of the target. The detector output given in digital counts need to be calibrated against the known thermal target. The feature is called as black body calibration. After completion of every full mode or normal mode scan the scan mirror collects the radiation from the black body whose temperature is available in the telemetry. The calibration test is carried out during the initial phase of the...
mission. Using the calibration data one can convert TIR video counts into the corresponding temperature which is called table look-up technique.

The total dynamic range of TIR channel has been arranged into convenient temperature ranges. The colour computing is achieved by assigning shades of selected colours to these temperature ranges. The newly created colour computing patterns are the indication of the TIR digital counts as shown in Figure. 3.3. The temperature range for corresponding infrared counts is from -90° C to 45° C.

![Figure 3.3 Mapping of Infrared counts into colour computing](image)

The image was created by applying the calibration to the thermal infra red digital counts to obtain the corresponding temperature. The different temperature ranges are indicated by the identified shades of contrasting colours. The meteorologists can readily read the sea surface temperature, cloud top temperatures, land temperatures, the abundance of water vapour etc from such images.

### 3.5 FORMATION OF LOOK-UP-TABLE

The VHRR instrument is a radiometer, designed to measure the intensity of the incoming radiation in defined wavelength bands. The acquired data from radiometer contain the digitized raw counts (sensor responses) in each wavelength band in a predefined format. The values being mere digital counts need to be calibrated against the known target.
TIR and WVP channels are accomplished after every imaging operation, by collecting one set of data while the scan mirror views the internal black body. Digitized raw counts from the data set correspond to the radiation received in each band from the internal black body, whose temperature is also recorded by four resistance thermometers as part of this data set.

The average of these four values gives \( T_r \) the black body reference temperature. The digital counts for each band are also averaged to get mean count DC.

The spectral characteristics of thermal emission from a body at temperature \( T^0 \) K are described by Plank’s law of radiation as given in equation (3.1) as:

\[
E_\lambda = \frac{2 \pi h c^2}{\lambda^5 \left[ \exp \left( \frac{hc}{\lambda K T} \right) - 1 \right]} \quad (3.1)
\]

where \( E_\lambda \) is the spectral radiant exitance in all directions, \( h \) is the Plank’s constant, \( c \) is the velocity of light (electromagnetic radiation) in vacuum, \( K \) is the Boltzmann’s constant, \( \lambda \) is the centre wavelength of the radiation band.

The satellite sensor measures the radiant flux from a narrow cone of direction and for infrared emission, the surface can be considered to be Lambertian with uniform radiance in all directions \( L_\lambda \) is given as:

\[
L_\lambda = \frac{E_\lambda}{\pi} \quad (3.2)
\]

Thus the emitted radiance from the internal black body reference as detected by the sensor at wavelength band is then calculated by reducing equation (3.1) as:

\[
L_{\lambda,r} = \frac{A}{\lambda^5 \left[ \exp \left( \frac{B}{\lambda T_r} \right) - 1 \right]} \pi \quad (3.3)
\]
By the classical approach (NOAA AVHRR) the calibration is carried out by collecting the data corresponding to two extreme temperature targets during every scan,

(1) While the scan mirror views deep space, beyond earth’s horizon. The temperature of deep space target is about 4º K (-269º C), which forms the data set corresponding to extreme low temperature. Let the radiance and the digital counts corresponding to the view be \( L_{s,\lambda, r} \) and \( DC_{s, \lambda} \) respectively.

(2) While the scan mirror views the internal black body after completion of every Full mode and Normal Mode Scans. The temperature of the target would be in the range of 283ºK - 323ºK (50ºC), which forms the data set corresponding to higher temperature. Let the radiance and the digital counts corresponding to the view be \( L_{b,\lambda, r} \) and \( DC_{b, \lambda} \) respectively.

With the values, the calibration is constructed, with gradient \( M_{\lambda} \) given by equation (3.4) as:

\[
M_{\lambda} = \frac{L_{b,\lambda, r} - L_{s,\lambda, r}}{DC_{b, \lambda} - DC_{s, \lambda}} \quad (3.4)
\]

and intercept \( C_{\lambda} \) given by equation (3.5) as

\[
C_{\lambda} = L_{b,\lambda, r} - M_{\lambda}(DC_{b, \lambda}) \quad (3.5)
\]

With these, the measured radiance \( L_{\lambda,m} \) for every digital count in the image for wavelength band \( \lambda \) can be obtained using the linear relation as given by equation (3.6).

\[
L_{\lambda,m} = M_{\lambda}(DC_{\lambda}) + C_{\lambda} \quad (3.6)
\]

The obtained radiance can be substituted in the plank’s equation (3.3) to obtain corresponding temperature, which is generally termed as brightness temperature.
The method of calibration for every individual imaging operation (scan) is a tedious and impractical implementation in a real-time process. In addition, the calibration constructed relied only on the two readings. The method of calibration which is generalized and would work all imaging operations (scans) has been improved upon as follows in an innovative way.

The trend of the temperature parameter of the internal black body that it varies from 15°C to 50°C over day. As the instrument scan is scheduled for every 30 minutes interval in normal mode, the TIR and WVP detector responses corresponding to black body view data during these every imaging operation is collected. All these data collected over the day were used to construct the calibration.

The diurnal temperature of the target black body varies only from 15°C to 50°C, whereas the cloud top temperature to be measured using this calibration ranges even below -70°C. Hence along with the readings obtained by viewing the target black body, the readings from the deep space view are also considered.

For various reference temperatures $T_r$ collected over the day, the corresponding emitted radiance $L_{\lambda,m}$ is computed using equation (3.3). With these values, the calibration is constructed, with gradient $M_{\lambda}$ given by equation (3.7) as:

$$M_{\lambda} = \frac{\sum (DC_{\lambda}L_{\lambda,m} - n\mu(DC_{\lambda})\mu(L_{\lambda,m}))}{[DC_{\lambda}]^2 - n[\mu(DC_{\lambda})]^2}$$

(3.7)

and intercept $C_{\lambda}$ is given as:

$$C_{\lambda} = \mu(L_{\lambda,r}) - M_{\lambda}\mu(DC_{\lambda})$$

(3.8)

where $\mu(DC_{\lambda})$ and $\mu(L_{\lambda,r})$ are the mean values of digital counts and the radiance respectively, $n$ is the number of samples collected. The measured radiance $L_{\lambda,m}$ in
each pixel of the image for wavelength band $\lambda$ is obtained from the linear construct as given in equation 3.9.

$$L_{\lambda,m} = M_{\lambda} DC_{\lambda} + C_{\lambda} \quad (3.9)$$

The value of $L_{\lambda,m}$ (measured radiance) for each pixel is interpreted in terms of brightness temperature $T_b$ the temperature of the perfect emitter which would produce that radiance if there were no intervening atmosphere. This is related to $L_{\lambda,m}$.

$$L_{\lambda,m} = \frac{A}{\lambda^5 \left[ \exp \left( \frac{B}{\lambda T_b} \right) - 1 \right] \pi} \quad (3.10)$$

It is not readily inverted to obtain $T_b$ from $L_{\lambda,m}$ instead (3.9) is used to fit a logarithmic curve of the form

$$T_b = m_{\lambda} \ln(L_{\lambda,m}) + c_{\lambda} \quad (3.11)$$

$m_{\lambda}$ and $c_{\lambda}$ being obtained by a least square fit. Hence a look-up-table to relate every possible value of $DC_{\lambda}$ to a value of $T_b$ is constructed from (3.8) and (3.10), and the complete image data set of wavelength band $\lambda$ is now calibrated in terms of $T_b$. The $T_b$ image can then be used as an indicator of temperature of the features of meteorological interest.

Computationally the more efficient than seeking to invert (3.9), since (3.10) need to be evaluated over only a finite dynamic range of temperatures corresponding to a finite range of digital counts. In the approach of creation of look-up-table relieves the real-time module of the system from enormous computations and intensive task of converting every acquired digital count into the equivalent temperature.
The colour computing algorithm for weather forecasting system consists of the following steps.

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**Colour Computing Algorithm (CCA)**

**Step 1:** Read the Thermal Infrared (TIR) image Data.

**Step 2:** Systematize the TIR channel dynamic range into convenient temperature ranges.

**Step 3:** Obtain the Temperature value for every pixel in the image using corresponding TIR digital count by look-up-table.

**Step 4:** Dispense the shades of selected colours to corresponding temperature ranges.

**Step 5:** Display the Enhanced Infrared (EIR) image.

The temperatures are calculated from the digital counts corresponding to the known area in the image using both the methods. The obtained temperatures are plotted with the in situ measured temperature of the area. The superiority of our calibration is evident from the least dispersion in the values with a correlation of about 94.5% as against the correlation of 59.4% obtained with the approach.
3.6 RESULTS AND DISCUSSION

The effectiveness of the proposed algorithm is demonstrated using computer simulation. The half hourly EIR images are derived from METSAT (KALPANA-1). Three data products are generated, i.e. VIS, TIR and WVP after completion of preprocessing procedure. Based on colour computing technique the TIR data processed and product generated as EIR in the next step. For each VHRR scan four image files are created. METSAT VHRR is scheduled for half hourly scans totalling 48 scans per day. This system has supported the weather prediction and cyclogenesis.

In the CCA, the important factor considered is image size for each of the bands working out to be 400 x 400 pixels to fit into the map for scene to scene comparison. Totally 2000 images acquired from the year of 2010 to 2014, including all kinds of images i.e. Lower cloud density, initialization of cyclone formation, mature cyclone etc.

Processed images are well suited for manual and further computerized analysis. This proposed algorithm is validated with more than 2000 images including 500 cyclone images. The following resultant figures 3.4 to 3.11 are different cyclone images of TIR with corresponding EIR images. The outcomes of the Colour Computing Algorithm are very useful for the precise weather forecasting and the severe cyclone formation is represented in colorful image. The Very Severe Cyclone formation is represented in red colour. The Colour Computing Algorithm is very importance for detection, forecasting the Severe and Very Severe Cyclones.
JAL cyclone TIR image is acquired on 7th November 2010 at 01:30UT is given to the input of the Colour Computing Algorithm (CCA). It is shown in the Figure 3.4(a). The corresponding Enhanced Infra Red (EIR) image after applying CCA is given in the Figure 3.4 (b).

Figure 3.4 (a) METSAT VHRR TIR image and (b) corresponding EIR image (JAL Cyclone)
The GIRI cyclone TIR image is acquired on 20th October 2010 at 23:30UT is given to the input of the Colour Computing Algorithm (CCA) as shown in the Figure 3.5(a). The Enhanced Infra Red (EIR) image after applying CCA is given in the Figure 3.5 (b).

Figure 3.5 (a) METSAT VHRR TIR image and (b) corresponding EIR image (GIRI Cyclone)
The JAL cyclone TIR image is acquired on 6th November 2010 at 01:00UT is given to the input of the Colour Computing Algorithm (CCA). It is shown in the Figure 3.6(a). The corresponding Enhanced Infra Red (EIR) image after applying CCA is represented in the Figure 3.6 (b).

Figure 3.6 (a) METSAT VHRR TIR image and (b) corresponding EIR image (JAL Cyclone)
The THANE cyclone TIR image is acquired on 25\textsuperscript{th} December 2011 at 17:30UT is given to the input of the Colour Computing Algorithm (CCA). It is shown in the Figure 3.7(a). The corresponding Enhanced Infra Red (EIR) image after applying CCA is given in the Figure 3.7 (b).

Figure 3.7 (a) METSAT VHRR TIR image and (b) corresponding EIR image (THANE Cyclone)
The THANE cyclone TIR image is acquired on 28\textsuperscript{th} December 2011 at 16:00UT is given to the input of the Colour Computing Algorithm (CCA). It is shown in the Figure 3.8(a). The corresponding Enhanced Infra Red (EIR) image after applying CCA is given in the Figure 3.8(b).

Figure 3.8 (a) METSAT VHRR TIR image and (b) corresponding EIR image (THANE Cyclone)
The Non-Tropical cyclone TIR image, acquired on 17\textsuperscript{th} August 2014 at 17:30UT is given to the input of the Colour Computing Algorithm (CCA). It is shown in the Figure 3.9(a). The corresponding Enhanced Infra Red (EIR) image after applying CCA is given in the Figure 3.9 (b).

Figure 3. 9  (a) METSAT VHRR TIR image and (b) corresponding EIR image (Non-Tropical Cyclone)
The HUD HUD cyclone TIR image is acquired on 8th October 2014 at 17:30UT is given to the input of the Colour Computing Algorithm (CCA). It is shown in the Figure 3.10(a). The corresponding Enhanced Infra Red (EIR) image after applying CCA is given in the Figure 3.10(b).

Figure 3.10  (a) METSAT VHRR TIR image and (b) corresponding EIR image (HUD HUD Cyclone)
The HUD HUD cyclone TIR image is acquired on 10th October 2014 at 17:30UT is given to the input of the Colour Computing Algorithm (CCA). It is shown in the Figure 3.11(a). The corresponding Enhanced Infra Red (EIR) image after applying CCA is given in the Figure 3.11(b).

Figure 3.11 (a) METSAT VHRR TIR image and (b) corresponding EIR image (HUD HUD Cyclone)
The enhanced IR images generated by METEOSAT-5 data are illustrated in the temperature ranges from \(-60^\circ\text{C}\) to \(+45^\circ\text{C}\). The processed information from only the Thermal Infra Red channel is encoded into these images.

The ‘Look-Up-Table’ based colour encoding approach is developed for enabling real-time generation of Enhanced IR images from the KALPANA data whose temperature ranges from \(-90^\circ\text{C}\) to \(+45^\circ\text{C}\). The processed information from two channels, namely Thermal Infra Red and Water Vapour is encoded into the images. The colour computing is organized more conveniently to indicate phase transition points of water in the clouds.

3.6.1 **Comparison of CCA Images with Metosat -5 satellite Images**

The images taken by the spacecrafts, for the same day and the same time were used for comparison. There was a good agreement in the temperature ranges of the features represented in both the images as shown in the Figure 3.12.

3.6.2 **Comparison of Processing Time with Metosat -5 satellite Image**

The Image data from the instrument of Metosat spacecraft are first received at primary ground stations at Fucino Italy, which is processed for various corrections. The processed data are encrypted and transmitted again through satellite link along with some administrative messages in L – band (1.7 GHZ) at 166.6 Kbps data rate. Authorized users will receive the processed data after about 30 minutes. The image update time in the case is (1) Instrument Scan Time + (2) Processing Time + (3) Re- Transmission time.

**Traditional METSAT (KALPANA-1) Images:**

The Image data from INSAT spacecrafts are received in extended C – Band (4.5 GHZ) at 526.5 Kbps data rate at the national facilities. The data are archived and processed for various corrections. The normalized data are then used for generation of the image products. The images in visible, thermal infrared and water
vapour bands are generated after a few minutes of the VHRR scan completion. The image update time in the case is (1) Instrument scan time + (2) Processing time.

![Image](image_url)

**Figure 3.12** Comparison results (a) Image generated by the proposed methodology (from METSAT-1 satellite) and (b) Image generated by Metosat – 5 (Credit: IMD)

### 3.7 SUMMARY

The technique mainly considered for pixel grid information to fit that of a map projection for scene to scene comparison, especially for weather forecasting system and cyclogenesis where pixel data comparison is more important. The proposed method is effective to be used for weather forecasting systems earlier than with traditional methods. The performance of the technique is further improved to near real-time image generations and accurately predict the intensity and identification of TC using EIR imagery. The Chapter - 4 deals with the Low Density Cloud Removal (LDCR) algorithm for Tropical Cyclone Eye location.