Challenges in development of signal extraction methodologies for Thermal Infrared Imaging Spectrometer (TIS) flown on Indian Mars Orbiter Mission

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ABSTRACT: India's maiden Mars Orbiter Mission, popularly known as Mangalyaan, carries a Thermal Infrared Spectrometer (TIS) based on Uncooled Micro bolometer detector array for generating thermal map of Martian surface. The associated processing electronics provides 20 bits digitized data containing both signal and background information. Extraction of useful signal from such a highly digitized data, poses great challenges in development of data processing methodology.

Various approaches have been studied to extract useful signal from the TIS instrument data and suitable methodology was implemented in the TIS image processing chain. The main challenge in the processing was to remove the background signal from the data. Detector case temperature (Tcase) correlation with the instrument data was determined using lab data and similar observations were confirmed with the onboard data also. Adequacy of Tcase dependence was studied from multiple data sets and finally image based correlation methodology was developed. A robust algorithm has been designed and developed for compensating the background and removing the pixel to pixel inherent non-uniformities. As a part of processing chain, image enhancement filtering techniques were also developed. The algorithm was verified over the simulated data sets, and subsequently implemented in the TIS data processing chain.

This paper covers the challenges involved in the instrument data processing methodologies to derive the useful signal. It also describes various steps involved in the processing chain, and discusses the algorithm validation processes involved and results obtained.

I. INTRODUCTION

India's science vision emphasizes planetary explorations for better understanding of the universe. The planet Mars has a special significance as it has many similarities with Earth and lies in the goldilocks zone of the solar system, where the thermal environment is suitable for the development and evolution of life forms. The Mars Orbiter Mission (MOM) was launched on 5th November, 2013 by ISRO's workhorse PSLV-C25, was India's first interplanetary mission and with this ISRO became the fourth space agency to reach Mars. MOM spent about a month in Earth's orbit, where it made a series of apogee-raising orbital manoeuvres before trans-Mars injection carried out on 30th November, 2013. After 298 days transit to Mars, it was successfully inserted into Mars orbit on 24th September, 2014. Five no. of scientific instruments, viz. **Thermal Infrared Imaging Spectrometer (TIS)**, Mars Colour Camera (MCC), Methane Sensor for Mars (MSM), Lyman-Alpha Photometer (LAP) and Mars Exospheric Neutral Composition Analyzer (MENCA), were flown on-board to explore the Surface, Atmospheric and Particle environment of Mars.

The Thermal Infrared Imaging Spectrometer (TIS) is one of the five instruments onboard MOM for the surface and atmospheric exploration using thermal remote sensing. TIS has been designed and developed around an un-cooled micro-bolometer array detector, to sense thermal radiation in 7-13 µm thermal Infrared regions. The more suitable Mercury Cadmium Telluride (MCT) based detectors require cooling, and therefore were ruled out due to weight and size constraints, whereas uncooled micro bolometer does not require any cooling. The signal to noise characteristics of micro-bolometer detectors (in terms of specific detectivity) is twofold less than that of MCTs and therefore it is not expected to give high measurement accuracy at high spatial and spectral resolutions.

II. THERMAL INFRARED IMAGING SPECTROMETER (TIS) INSTRUMENT

In order to cater to the application requirements, TIS spectrometer design consists of fore optics, slit, collimating optics, plane reflection grating and focusing optics. Fore optics illuminates a slit placed at its focal plane which defines the input to the spectrometer. A collimating lens provides the collimated beam to the grating which disperses the energy into different wavelengths. The first order spectrum of the dispersed beam is then refocused by means of a focusing lens. An area array micro-bolometer consisting of 160 pixels (spatial) x 120 pixels (spectral) with 52 µm pitch and size of 50 µm is placed in the focal plane to collect the dispersed energy. By binning pixels in the along-track direction, it is configured to 160 pixels x 12 spectral bands. This makes the effective 20-bit digitized video output. Figure-1 represents an optical schematic of the TIS instrument.

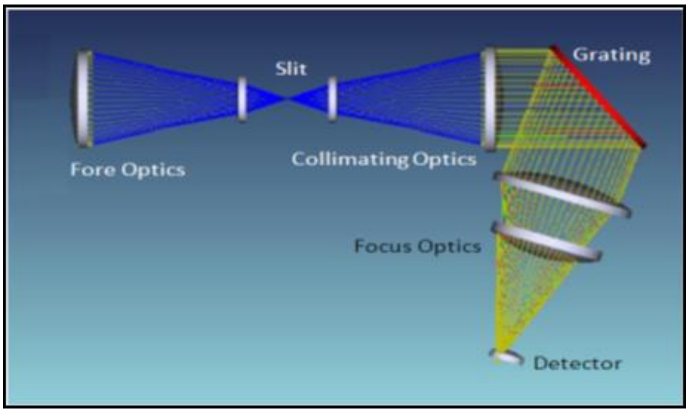


Figure-1: Optical Schematic of TIS

This detector is integrated with the ROIC, Thermo Electric Controller (TEC) and temperature sensor. The vacuum sealed AR coated germanium window of the detector allows the IR radiation within 7-13 um band only to transmit through it.

The detector has two analog output (video) VOUT and TCOMP (Detector Die temperature) corresponding to active and blind pixel output respectively. The outputs are digitized using 16-bit digitizer, DPE (Detector Proximity Electronics) along with TEC controls, in feedback loop. The detector package temperature (Tcase) on the side of Detector Cover mount is monitored using a chip transistor.

Figure-2: TIS Instrument

During P/L development level, correlation of video data to die temperature (Tcomp) and video data to detector case temperature (Tcase) correlation were studied. It was observed that detector video data was better correlated to detector case temperature compared to Detector Die temperature. Accordingly it was decided to continuous monitor the detector case temperature. A lab model of instrument flown on MOM is shown in figure-2.

III. TIS OPERATIONS CHRONOLOGY AND DATA COLLECTION

Before reaching the Mars, the MOM spent 10 months to its voyage. Based on the mission terminology, the TIS instrument was switched on during different. These phases are shown in figure-3.

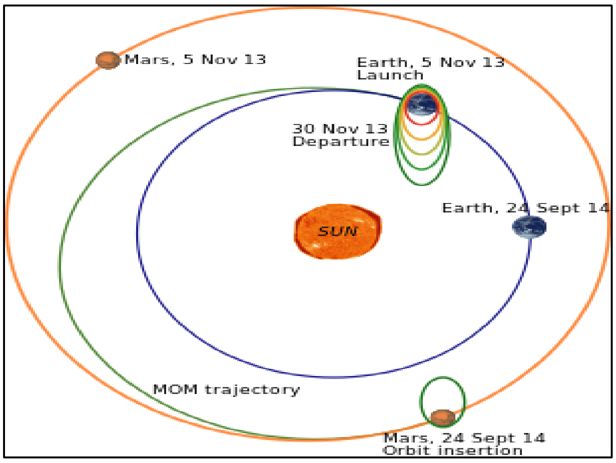


Figure-3: Various phases of MOM during its voyage towards the Mars

Geocentric phase
On 23rd November, 2013 TIS was switched on for the first time. Within the limited scope for imaging, TIS was operated twice to capture Earth's data.

Heliocentric phase
MOM was put in trans-martian orbit on 30th November, 2013 on its long journey towards Mars. During this cruise phase TIS was again switched on few times. Deep space imaging was carried out to verify the instrument's overall performance and consistency. In this phase the TIS instrument was operated to collect the Deep space look data.

Around Mars
As planned and expected, MOM was inserted into a highly elliptical orbit around Mars on 24th September, 2014. Taking into consideration the orbit and Mars-Sun alignment, Mars was imaged initially from Apoareion and gradually the imaging locations moved nearer to Mars. The statistics of acquisitions are represented in Figure-4.

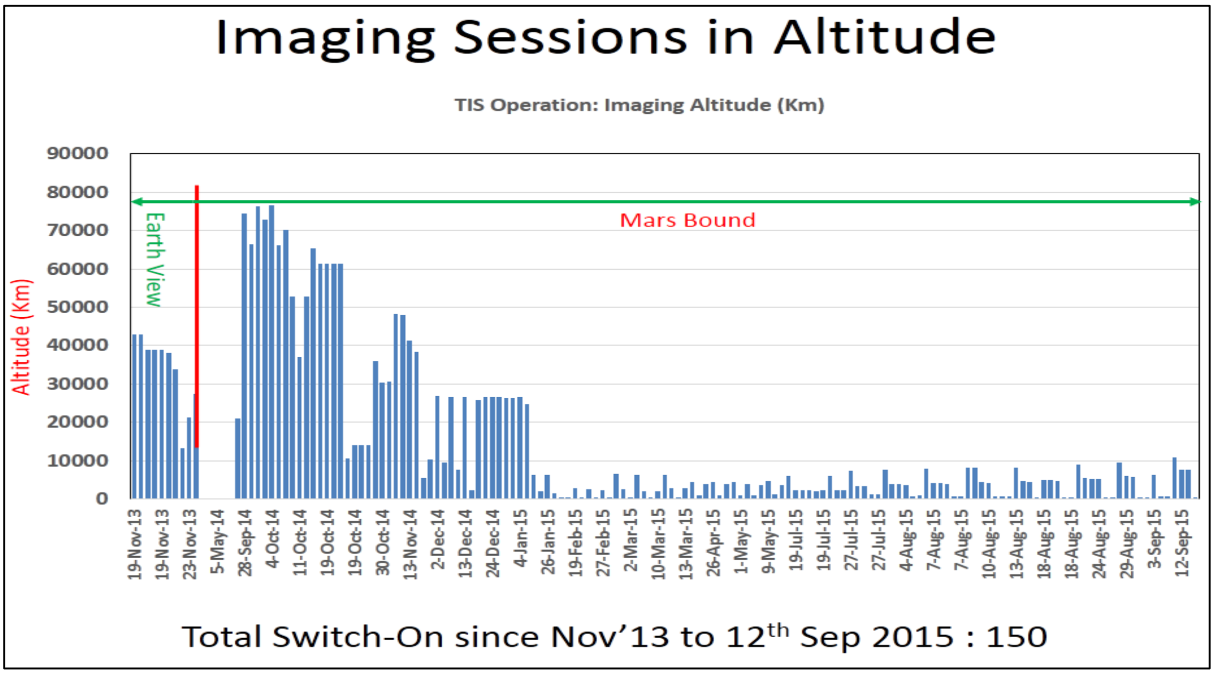


Figure-4: Acquisition Statistics around Mars

IV. TIS CHALLENGES IN DATA PROCESSING

Push broom imaging techniques is used to scan a specified region during the imaging. The each line data as acquired during imaging, consist of 12 no. of bands, 160 pixels across with pixel count of the order of x10^5 for deep space and surface, but the detection sensitivity of the instrument could not be of such a high DN value. This implies that the Bolometer output is dominated with background, with signal of interest being few orders lower, i.e. deeply buried in the background. In this operating mode the video data is accompanied with Tcase data as well, which is representative of the Bolometer temperature at the time of imaging. The experiments carried out under controlled environment during sensor development, had shown extremely good correlation of Tcase data with video data for many of the imaging sessions.

To analysis the data further, it was first corrected for line drops and Bad pixels. The standard median filter approaches with kernel size of 5 samples were considered. Thus a Raw Image for deep space data (uniform and equivalent to 4K degC) and Martian surface looking data (non-uniform and varying temperature, with mean ~250K degC) are shown in figures-5 a & b. This shows that the bolometer output is dominated with background or it may be treated as the signal is deeply buried in the noise.

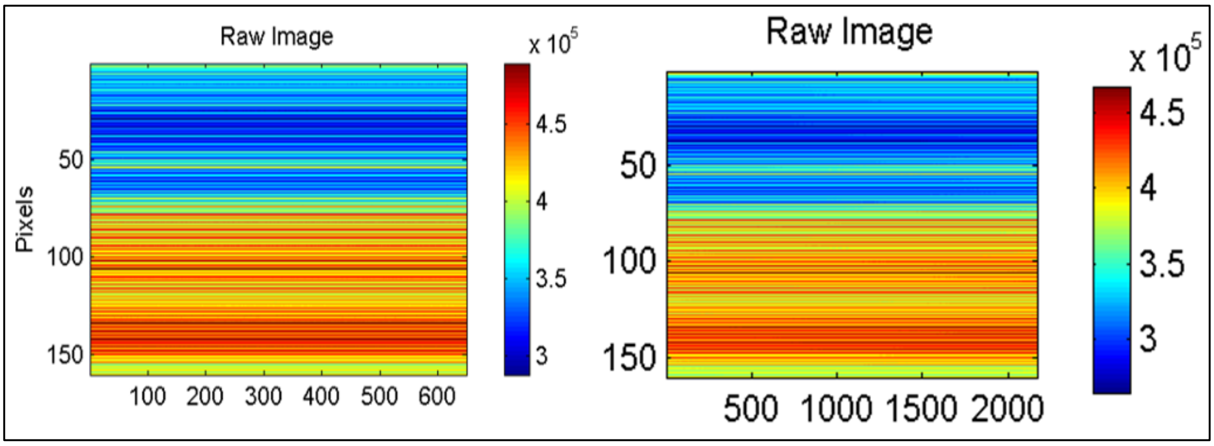
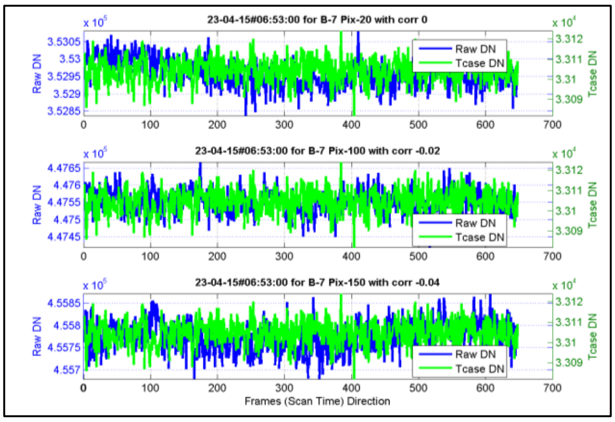


Figure-5a: Deep Space image for 23rd Apr'15 5b: Martian Surface image for 23rdApr'15

To extract useful signal from the TIS instrument data, various approaches have been studied both in spatial and in frequency domain. The deep space data acquired in Geo-centric, Heliocentric (cruise phase) and Mars bound phases are not identical. Even the various deep space (dark) data acquired in Mars bound phase having non-identical characteristics for both video and Tcase, though it depends on the Electro-Optical Module (EOM) as well. A typical case for dark data to Tcase correlation is shown in figures-6 a & b. The Tcase raw data has –ve DN to temperature conversion coefficient, Tcase (degC) to dark and Video data relationship is shown in figures-7 a & b. It can be clearly observed that the in this case dark data correlation with Tcase (degC) is very insignificant here, but in many cases reverse were true. It can be seen from figure-9a & 9b, that there is significant correlation between raw Tcase & dark data but the value is quite large in case of video to Tcase correlation.



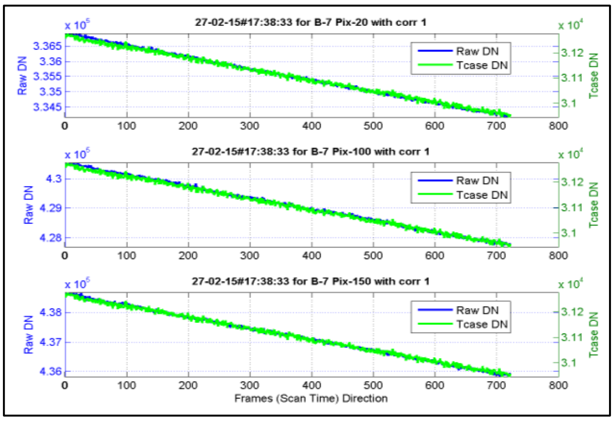
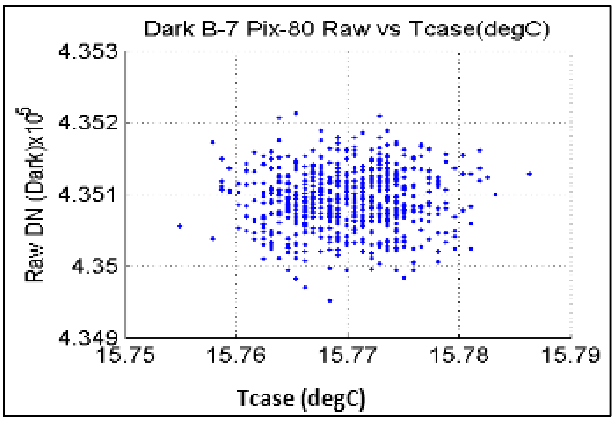


Figure-6a: Dark and Tcase data correlation for raw data at 3 different pixel locations23rd Apr'15
Figure-6b: 27th Feb'15

Analysis of various data sets shows that there is an inherent drift in the data and therefore, to extract the useful information from such spatially drifted data, this drifted has to be corrected in its preliminary stage. Since the video data (instrument data) drift to Tcase correlation is not identical and Tcase is not true representative for all the pixels, hence drift estimation wrt to Tcase is not suitable for true video data estimation.

Additionally, the non-uniqueness of video data drift (varying slope) over each individual data, limits the conventional methodologies for such drift correction. It would be more appropriate to apply the data driven approach for such cases.



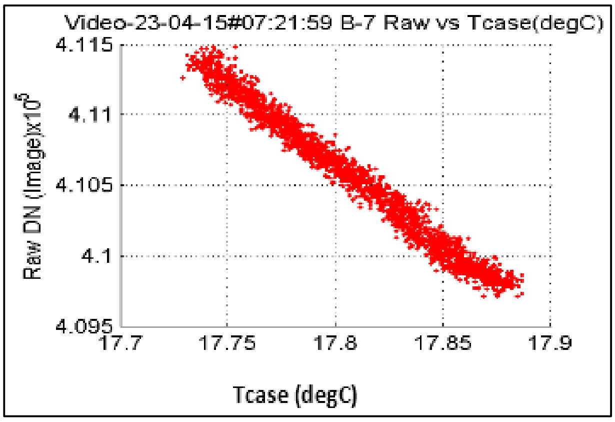


Figure-7a: Dark Raw Dark and Tcase (degC) data correlation for Pixel-80 23rd Apr'15
Figure-7b: Dark Raw Dark and Tcase (degC) data correlation for Pixel-80 23rd Apr'15

V. SIMULATION RESULTS AND DISCUSSIONS

The critical challenge in the data processing and extraction of the signal, were correction for the data drift, removal of the background, correction for stripes and last but not the least the validation of the process. Tcase correlation with the instrument data is also analysed for lab data. The similar signature of drift in lab data and on-board data confirms, this as an instrument inherent characteristics.

Adopting the data driven methodology, Drift estimation is carried out for each spectral band and each pixel separately. The linear regression and offset selection, over the pixel wise mean removed data, improves the accuracy by many folds. Drift correction process is carried out on both Dark and Video data separately.

Drift estimation and correction process with along track and across track profiles are shown in figure-8. Dark and video data profile for raw data drift corrected data are shown in figure-9 a & b.

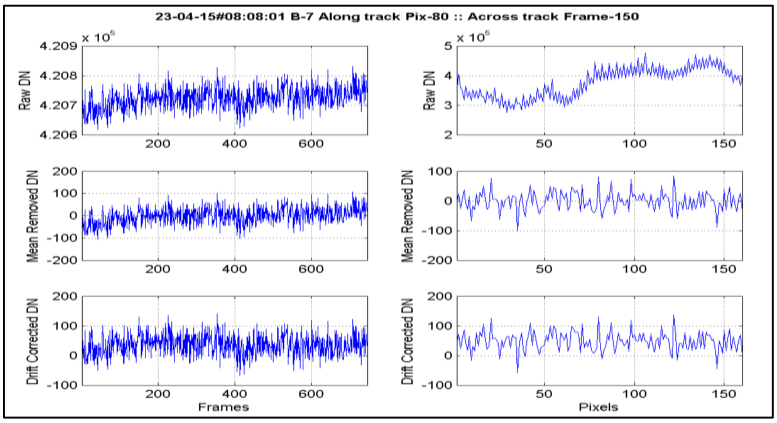
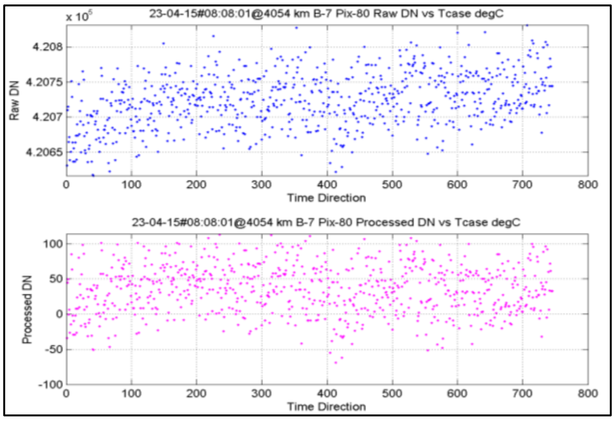


Figure-8: Video data drift estimation and correction

Multiple data sets were studied to get an appropriateness of Tcase dependence and drift correction. It has been found that the data driven methodology, as illustrated in figure-7 is sufficiently good. This image based drift correction relationship was the basis of estimating the background and extraction of video data.



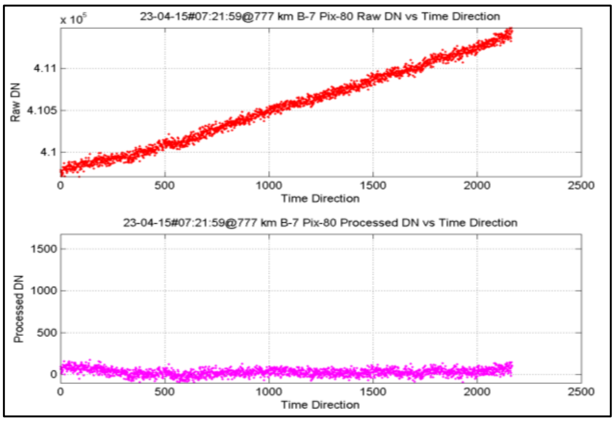


Figure-9a: Dark and Tcase correlation (raw level) and same for drift corrected data, pixel-80
Figure-9b: Video and Tcase correlation (raw level) and same for drift corrected data, pixel-80

VI. BACKGROUND ESTIMATION & COMPENSATION

Subsequent to the processing steps as described earlier, the instantaneous observations of each pixel in time direction is obtained, which comprises the contributions from scene (either deep space or Martian disk) and noise. To correct the basic offset, the mean of N-frame (drift corrected data), has been subtracted from the entire drift corrected dark image. This reduces the effective number of frames by N. In case of dark image (deep space), it is not very significant.

A 3D profile of deep space (dark) data with all the discussed processing steps is compared with raw data in figure-10.

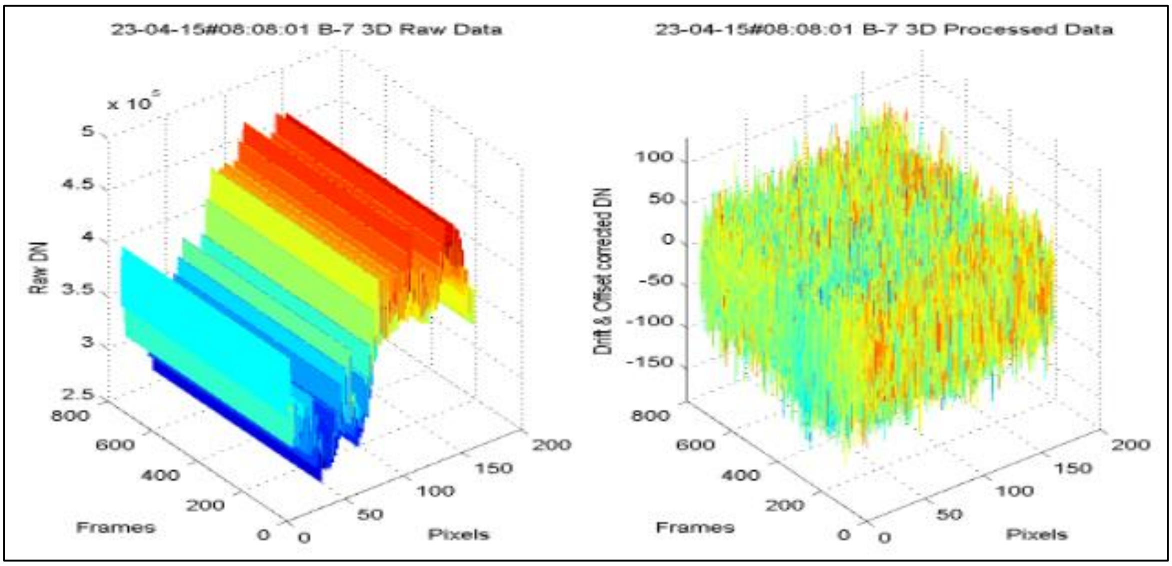


Figure-10: 3D-profile of Dark data (raw) and processed data

Background estimation is carried out for every pixel of each band from the deep space data (dark data). For dark Image, background is estimated from drift corrected data by considering initial ~60 frames;

The steps involved in processing of actual scene data from Mars are also same as that of Deep Space image. However, the processed deep space image is treated as dark data. The dark data is then subtracted from processed scene data. In case of isolated dark and video data sets, the background estimation is carried out over all the dark frames.

VII. NON-UNIFORMITES CORRECTION AND IMAGE ENHANCEMENT

All the processing steps, has been implemented for TIS data processing chain and a robust algorithm has been developed for compensating the background. The resultant image from above steps is still left with noise that could not be modelled. Additionally, existence of pixel to pixel non-uniformities, due to inherent nature of detector array, shows various stripes in the images. To mitigate such limitations of non-uniformities and in order to enhance the image, image enhancement filtering techniques viz. Histogram Matching, Power Spectral Density (PSD) based Low Pass Filters were developed, and a PSF based Gaussian filter were applied for de-striping. These methods are discussed in Reference-5, “A Technical Note on TIS Image Generation”, and a PSF based Gaussian filter is applied.

Based on the fundamental theory of the sensor (Bolometer used in TIS), its response reduces with increase in temperature. Thus as a slandered representation the relatively higher temperature scene as red than the lower temperature scene (as blue), the images produced by offset subtracted data, were reversed in sign. If still any negative DN found in image, the entire image data is fixed biased to the global image minimum.

Applying the discussed algorithm, and image enhancement filtering to the raw data, deep space and a Martian scene images are shown in figure-10a and 10b.

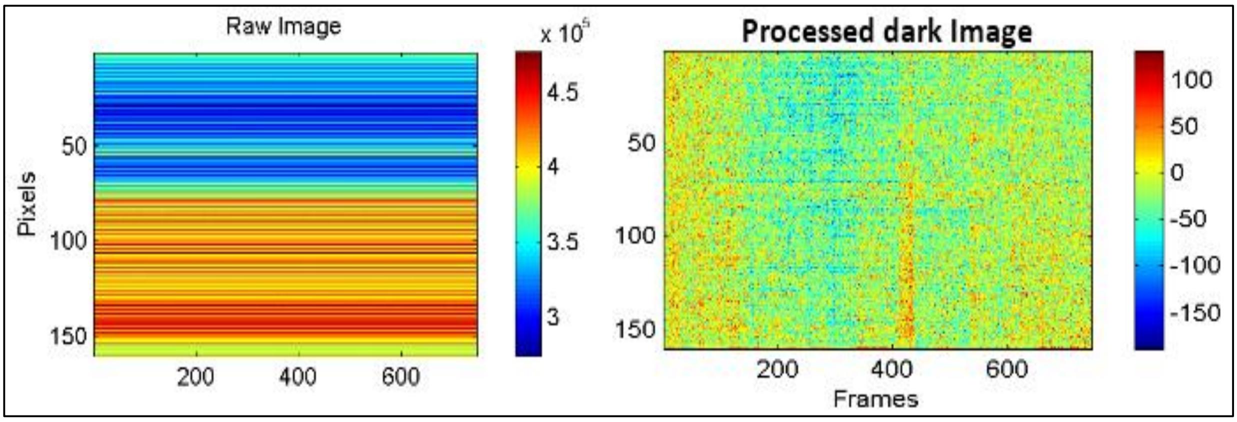


Figure-10a: Deep space Image-Raw Image and Processed Image for 13th Apr’15

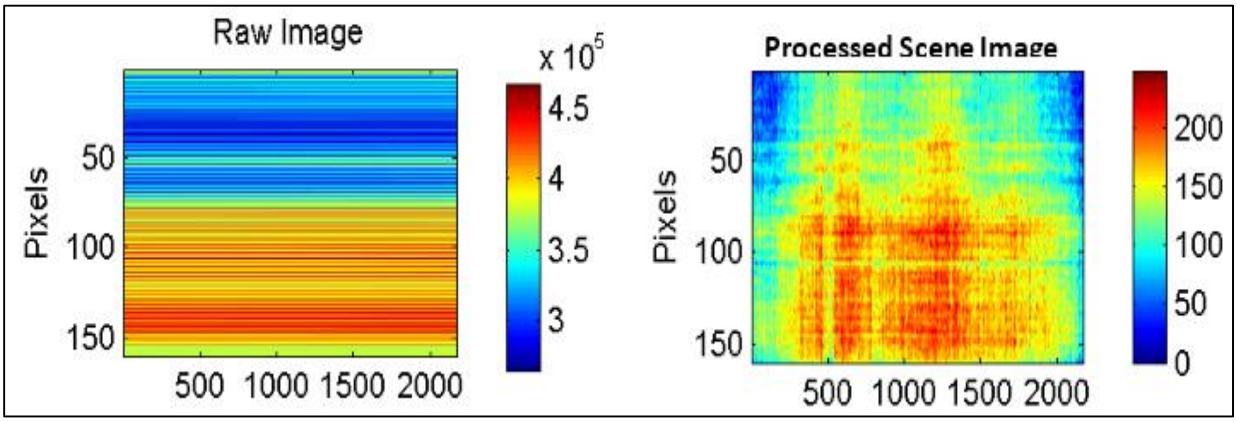


Figure-10b: Martian surface looking Images-Raw Image and Processed Image for 13thApr’15

Further, Oversampling Correction (if any) followed by aspect ratio correction is implemented. The final image with all corrections including smoothing is shown in figure-11.

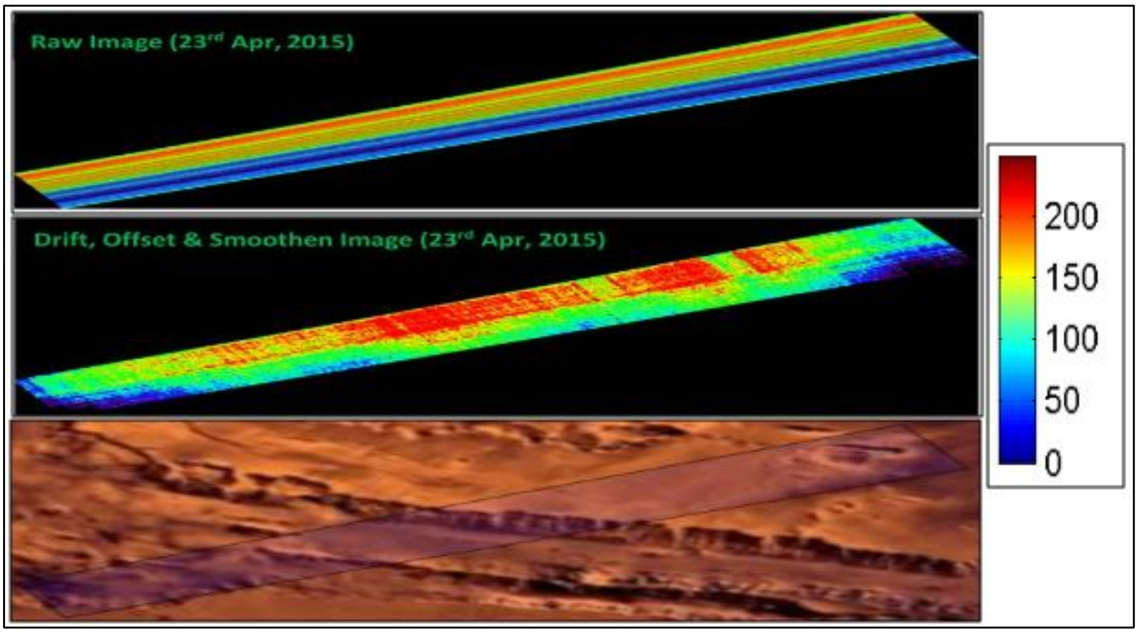


Figure-11: Martian surface looking Images-Raw Image, Processed Image and an overlaying imaging strip MOLA data (top to bottom), for 13thApr'15

VIII. RESULTS AND CONCLUSIONS

This in-house developed algorithm has been verified over the simulated data sets; by inserting a known pattern in the raw deep space data and by successfully recovering of the same pattern. The validated algorithm was subsequently implemented in the TIS data processing chain.

The process described, highlights the various challenges encountered during the Digital image generation from the data acquired by an uncooled thermal detector. Data analysis over carried out over various data sets, prominence the data driven approaches which are differ from the conventional techniques.

The algorithm validation and the background work for deep space data analysis shows consistency and matches very well with lab acquired data. The algorithm described is able to generate images at count level. The thermal image can be generated using the proper calibration data.

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REFERENCES

1. Technical Note on TIS Image Generation Algorithm: By Jitendra Kumar, PCSVD/PCEG/SEDA
2. Processing of Thermal Infrared Imaging Spectrometer Data: By Jitendra Kumar, Ashish Mishra and S S Sarkar.
3. Space Applications of Thermal Imaging Sensors and Stripes Corrections challenges in its Images.
4. Digital Image Processing, Using MATLAB, by Rafael C. Gonzalez, Richard E. Woods, and Steven L. Eddins.
5. Image Processing Toolbox, For Use with MATLAB (MATLAB's documentation)—refer online at: http://www.mathworks.com/access/helpdesk/help/toolbox/images/