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HPC for SAR-MSS Data Fusion Experiments

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Abstract

Satellite image fusion techniques are compute intensive models mainly due to the availability of voluminous temporal data from multiple sensors. The need and support of High Performance Computing clusters in modelling various satellite data fusion techniques is unavoidable as the 5V's such as volume, velocity, variety, value and veracity of space based Big Data has to be scientifically integrated over a HPC environment. Any such integration is meaningful, only when a suitable domain specific parallel processing algorithm is developed that can extract the much required critical information in near real time or real time mode. In this regard, this article mainly focuses on defining a HPC system environment and corresponding parallel algorithm which together supports the image fusion experiments of various space borne satellite data sets. Emphasis has been given in fusing different frequency, polarization Synthetic Aperture Radar's, intensity data with Multi Spectral optical satellite data. The well proved and most commonly followed IHS and PAC image fusion techniques are studied and its parallel version of algorithm that can be enabled over the proposed HPC environment are discussed. In the current world scenario, setting up the proposed HPC system and enablement of proposed parallel models are unavoidable, mainly to address the real time requirements of defense and disaster management operations.

Keywords: *High Performance Computing (HPC), Synthetic Aperture Radar (SAR), Multispectral Scanner (MSS), Image Fusion, Intensity–Hue–Saturation (IHS), Principal component analysis (PCA).*

INTRODUCTION

In space research, across the globe many earth imaging remote sensing centres are under continuous pressure of enhancing their computing system setup, its related software stackas well as in developing much enhanced algorithms due to ever increasing nature of space and airborne temporal data which are available from multiple sensor sources. Space centres of developed nations such as NASA (National Aeronautics and Space Administration), ESA (European Space Agency), DLR (Deutsches Zentrum für Luft und Raumfahrt - German), JAXA (Japan Aerospace Exploration Agency), CNES (Centre national d'études spatiales - France) and few developing nations including India had already moved their data capturing and storage mechanism into secured HPC environment. The data generation rate of such imaging sensors in each year is already touched to petabytes storage level [5]. Processing of such voluminous data is feasible only by the labs which are equipped with High Performance Clusters (HPC) as well as corresponding specialized software processing environment. Many space labs are continuously upgrading their own software stack that can retrieve and compute the Big Data of multiple space sensors as per end users requirements. In line with this, this article discusses the data management aspects of HPC labs that specially supports image fusion experiments of Synthetic Aperture Radar (SAR) and Multispectral Scanner (MSS) data.

Section-2 of this article brings out details about proposed specialized Image Fusion HPC system that can be setup mainly to support the data fusion experiments of different frequency, polarization Synthetic Aperture Radar (SAR) datasets of various global SAR satellites with Multispectral Scanner (MSS) data sets. Section-3 which is the core theme of this article brings out the details of proposed software algorithms which can be implemented in a parallel mode over the proposed system setup. The concluding section brings out the significance as well as advantages of the setting up the proposed HPC based image fusion system in operational mode.

SYSTEM OVERVIEW

The proposed image fusion setup that can support the data fusion between SAR and MSS data sets over a HPC environment is shown in Fig.1. In the beginning the end user has to identify region specific data sets from the storage units. While executing, the simulation model requires computing nodes in dedicated mode. This can be achieved by developing a domain specific data fusion workflow tool which can communicate between the storage clusters and computing clusters. The HPC middleware stack which includes Job submission, scheduler and monitoring tools which are integrated with this workflow tool, guides and monitors the image fusion simulation as and when the nodes are made available in dedicated mode.

In the context of SAR raw data calibration, the complex math components that act behind the processing of binary satellite SAR signals into SLC data is beyond the scope of this paper as the same has been well proved by [3, 4, 6, 7]. These references explain the process details of raw data conversion into SAR SLC (Single Look Complex) data which in general indexed into the storage units of the clusters as Level-1 data. SAR and MSS data sets of all sorts cannot be fused. Data covering the same geographical region with appropriate resolution has to be narrowed down. Moreover when SAR data is being used as an intensity channel, down scaling of SAR data from 16 bit into 8 bit data has to be taken care. In addition to this, at the time of SAR SLC to image conversion the multi-look parameters have to be in sync with the resolution of MSS data so that image fusion between high spectral intensity and high resolution data can be taken care [1]. All these processes have to be achieved by developing an application specific pre-processing workflow that needs to be invoked before executing the fusion algorithms. Cross validation of image specific parameters can also be added by developing a look-up table which cross checks the fusion compatibility between SAR and MSS data sets.

In addition to above, the primary advantage of opting satellite SAR is availability of data in various polarizations. As shown in Fig.1 depending upon the SAR satellite configuration it is feasible to derive Single Polarization data (SP) of HH or VV (HH: microwave radar signals transmitted Horizontally and received by sensor in Horizontal mode or VV radar signals transmitted Vertically and received by sensor Vertical mode); Dual Polarization data (DP) of HH/HV or VV/VH; Compact Polarization data (CP) of RH/RV; Quad Polarization data (QP) of HH/HV/VH/VV and Quasi-Quad Polarization data (QQP) of HH/HV and VH/VV. Finer details about DP, CP, QP, QQP can be seen in [2, 8]. Availability of all these polarization data from a single satellite is hard to be achieved. In general Satellite SAR which was launched before 2000 were capable of generating Single and Dual polarization images. Future satellites which are expected to generate enhanced Compact and Quad polarization data are NISAR and Tan DEM-L of which the first one senses the earth surface both at L- and S-band frequencies whereas the second one generates data at L-band frequency [9]. Overall, petabytes of data is already generated by existing satellites and in addition to this petabytes of multi polarization data will be available from future SAR satellites [2,8]. Such Big Data having the characteristics of Veracity, Variety, Velocity, Volume, Validity, Variability, Volatility, Visualization and Value can only be stored in HPC storage clusters. SAR-MSS image fusion experiments with all possible characteristics options of different frequency, polarization can only be achieved when the respective model is built over a HPC environment (Fig 1).

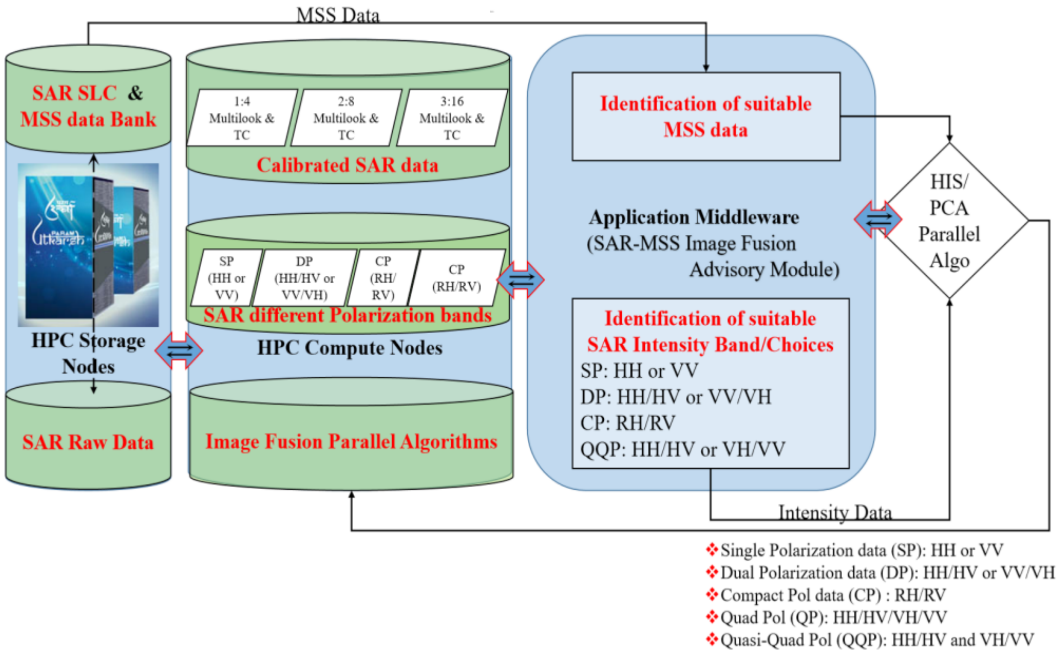

Fig 1. Proposed HPC System environment for SAR-MSS Big Data Fusion Techniques

SAR-MSS IMAGE FUSION ALGORITHMS

This article mainly brings out the details of Intensity-Hue-Saturation (IHS) and Principal Component (PCA) data fusion techniques experiments using satellite SAR and MSS images. IHS and PCA are the most followed fusion techniques in the image processing domain. Other fusion techniques such as Pyramid techniques, High pass filtering, Wavelet Transform, Artificial Neural Networks and Discrete Cosine Transform are dominant in the R & D stage which requires extensive post validation especially when used in operational scenarios.

IHS Image Fusion Technique

Intensity-Hue-Saturation (IHS) are the three properties of a Multi Spectral image (MSS) which decides the controlled visual representation of an image. IHS fusion is the basic or fundamental level of fusion technique in which the R (Red), G (Green) and B (Blue) bands of the multispectral image undergo transformations at **I**ntensity-**H**ue-**S**aturation levels. In general the 'I' component is controlled by spatial information and H and S components are controlled by spectral transformation. During this IHS based image fusion process, the Intensity component is replaced by the information content of high resolution data and subsequently an inverse transformation is performed mainly to get a much enhanced multispectral image with high spatial resolution. Image fusion between intensity SAR image with Multispectral optical image is shown in Fig.2. It is very much possible to have an integrated MSS+SAR and MSS+Panchromatic (PAN) image fusion model as shown in Fig.2 and in Fig.3. In both these figures, details of using PAN (Panchromatic image of 8- bit data, from optical sensors) image is mainly retained to showcase how the intensity SAR image can be an effective alternative to intensity PAN image.

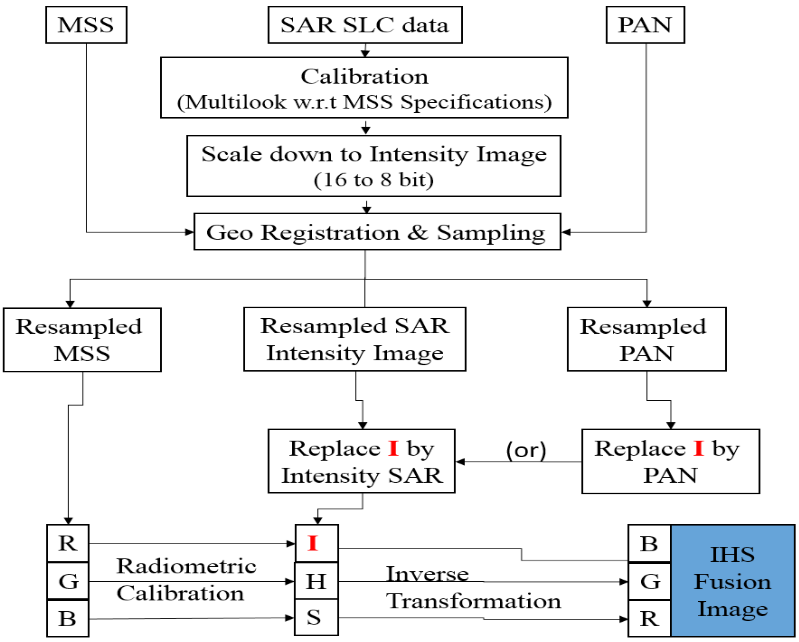

Fig 2. Schematic diagram represents the processes involved in MSS-SAR and MSS-PAN of IHS Image Fusion Technique

PCA Image Fusion Technique

Implementation of Principal Component Analysis (PCA) for any application model, performs a set of orthogonal transformations by which the information content is maximized along linearly uncorrelated orthogonal planes of PC-1, PC-2, PC-3...PCn. Each one of these Principal Component planes are perpendicular to each other. In image processing, the PC-1, PC-2 and PC-3 planes are generally derived using multispectral channels of the image. During the PCA image fusion process as shown in Fig.3, the PC-1 channel is transformed with the intensity information of a high resolution SAR and subsequent to this a reverse PCA transformation is performed. This technique is expected to produce a much enhanced image than the earlier IHS technique as information at three different perpendicular axes is fused with maximum possible variation.

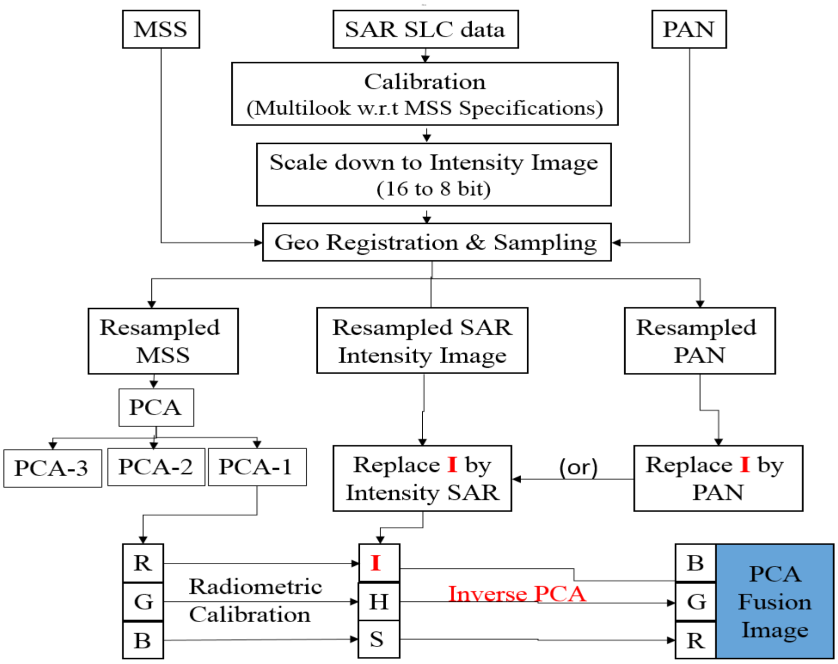

Fig 3. Schematic diagram represents the processes involved in MSS-SAR and MSS-PAN of PCA Image Fusion Technique

HPC algorithm for Data Fusion experiments of SAR-MSS Big Data

As shown in Fig.1, SAR and MSS based data fusion techniques can be achieved through multiple permutation and combination of different frequency and polarization data sets. The different polarization options are shown in the legend of Fig.1 which can be sourced from C-, L- and S-band SAR frequency channels. As on date getting all this data from a single satellite is not feasible but data of the same geographical region of different time stamps from different satellites can be fused as detailed in earlier sections. Any such compute intensive Big Data model can only be executed over a HPC environment with the support of application specific parallel algorithms. In this regard, suitable HPC system setup is already detailed in Fig.1, and corresponding parallel algorithm is shown in Fig. 4. Over, a HPC environment (Fig.1) the SAR-MSS data fusion techniques (detailed in Fig 2 and 3) can be enabled by following a parallel algorithm model as shown in the following Fig.4.

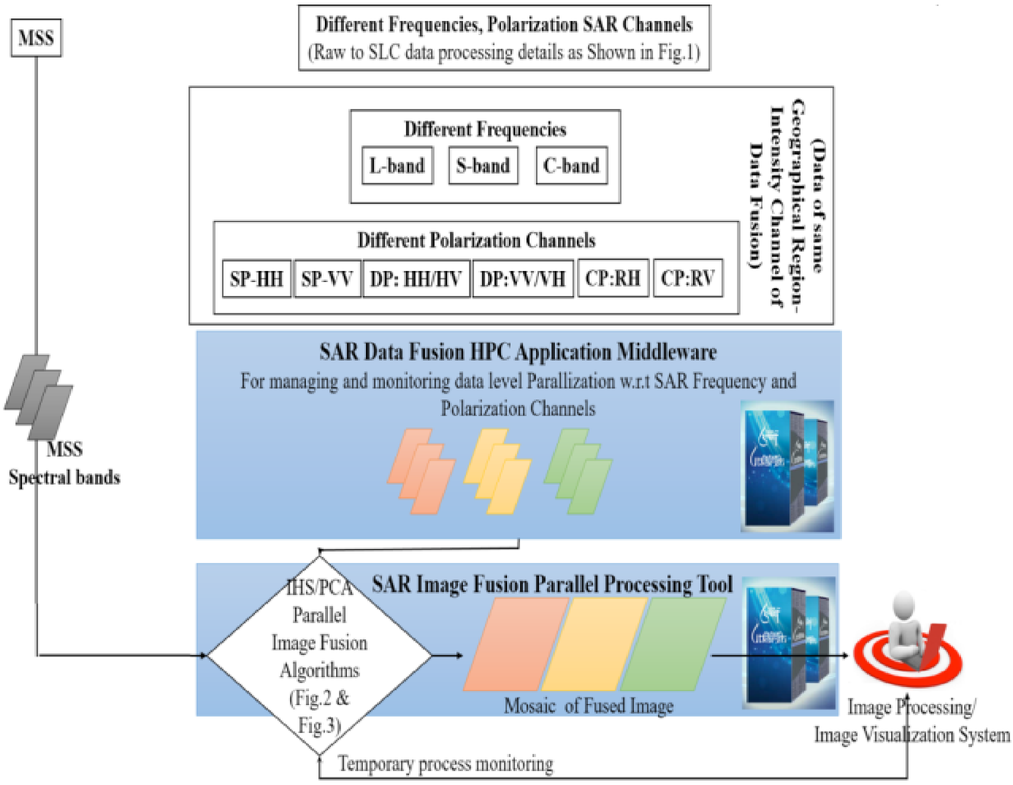

Fig 4. SAR-MSS data level HPC Fusion Algorithm

As mentioned in the beginning a middleware pre-processing tool initially compares the suitability of MSS band and SAR intensity band and ensures both the data are of the same geographical region. Subsequent to this, it will redirect each polarization channel of individual SAR frequency band along with MSS spectral band to the allotted computing resource for the further processing. At computing nodes either IHS or PCA data fusion algorithms will be executed as per the choice of the end user. As and when required, from the job submission environment, the process details are monitored by the end user who is a domain expert and intermediate results are periodically validated with the help of an Image Processing server as shown in Fig.4. After the data fusion the equivalent images are automatically segregated based on the image metadata information and time stamp which are part of the header information of each output image. An automated mosaic tool will be executed at the visualization node which mosaic the output images based on the updated header information preserved in each processed image. The final fused image can be visualized with the help of an Image Processing System and further interpretation can be carried out.

CONCLUSION

Serial versions of image fusion techniques between SAR and MSS data sets were demonstrated by various research publications. This article focuses on bringing out the details about parallel versions of image fusion techniques over a HPC environment by insisting in setting up an operational version of HPC based data fusion clusters which can support voluminous Big Data fusion experiments of SAR and MSS sensors. Practical use of such operational setup will be a boon to the defense as well as disaster management operations as the much required critical information can be derived within lease possible time duration. However, field validation of the proposed model results are yet to be validated over different terrain conditions as SAR sensors are capable of capturing the terrain information round the clock whereas MSS sensors are sun synchronized in nature which can only capture the earth surface information during the day time.

More experiments in this line will improve the interpretation level of terrain that has been studied as well as expected to improve the textural characteristics and understanding of the objects that need to be predicted as well as monitored in real time mode. Setting up the proposed HPC system will be a boon to the sectors which deal with real time operations such as Defense, Disaster Management and other fields of Geospatial applications.

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