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3D Volumetric change analysis in urban areas

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Abstract: Urban planning demands a comprehensive understanding of urban development for efficient designing and expansion of urban areas. The 3- D model of urban area are popular among the urban planners. This study involves the development of 3-D model for part of Ahmedabad city for two time periods, year 2005 and 2015 and analyse volumetric change in urban development in one decade. The Digital Elevation Model (DEM) is generated using CARTOSAT-1 stereo pair data with 2.5 m spatial resolution for year 2005 and 2015. The building footprint is extracted for the study area from very high resolution merged product of CARTOSAT-2 series data using object based image analysis approach. The height is extracted from the generated DEM for year 2005 and 2015. The base height is extracted from the buffered area of 25 m around the buildings to extract the actual building height. The volumetric change in buildings in one decade is calculated by subtracting the building height of 2015 and 2005. The volumetric change in buildings are categorised into three types, i.e. reconstructed, new construction and unchanged built-up. The volumetric change in percentage for new construction, reconstruction and unchanged built-up areas are 4.47, 10.0 and 85.53, respectively.

Keywords: Building footprint, Volumetric change analysis, Stereo-pair data, Object based image analysis

1. Introduction

Urban planning demands a comprehensive understanding of urban development for efficient designing and expansion of urban areas. The effectiveness of planning is majorly contributed by the analysis of urban growth pattern. The 2-D map of urban areas limits the capabilities of visualization of 3-D urban structures. Hence, the 3-D model of urban area becomes increasingly popular among the urban planners. With the increase in populations and less availability of vacant land spaces, the city is rapidly expanding with tall structures. The integrated GIS and 3D volumetric analysis enhances the capabilities of urban planning and management (Haralik et al., 1973).

The 3-D volumetric analysis is beneficial in case of disaster events like flooding, earthquakes and tsunami. They play a vital role in the rescue operations for the development of the strategic planning which helps people to be rescued effectively (Kolbe et al., 2005). Most of the available sources for building 3-D model such as stereo aerial images, airborne LiDAR data, etc. are expensive when required to cover large urban area. The availability of very high resolution satellite data for large urban areas helps to investigate them in a fast and inexpensive manner. (Sharma et al., 2016).

In this study, 3-D model for two time periods for year 2005 and 2015 is generated for the study area and volumetric change analysis in urban area is analysed in one decade. The building footprints were extracted from a very high resolution fused multispectral data of CARTOSAT-2 series using object based image analysis approach. The elevation information is extracted from the digital elevation model generated from CARTOSAT-1 stereo pair data for year 2005 and 2015. The volumetric change from 2005 to 2015 is analysed and is categorised as new construction, reconstruction and unchanged classes.

2. Study area

Ahmedabad is the fifth most populous city of India with population of 55,77,940 as per the census of 2011. It is also the seventh largest metropolitan city of India. The city is geographically located at mean latitude of 23°02’25’’ N and longitude 72°57’14’’ E. It is major centre for trade and commerce in the western part of India. The city comprises of commercial, residential and educational structures. The study area is one of the sub-urban part of Ahmedabad. It comprises of congested residential and commercial structures within past few years, the development of this area took place during recent times and new high-rise residential buildings, commercial structure and educational institutes were developed. With the massive development, this study area is suitable for studying the horizontal and vertical expansion of the city (Figure 1).

3. Data used

The data used for the study is acquired by Indian Remote Sensing Satellite (IRS) launched by Indian Space Research Organisation (Table 1). CARTOSAT-2 series satellite provide panchromatic and multi-spectral (Red, Green, Blue and NIR) bands with spatial resolution of less than 1 m and 1.56 m, respectively. The merged product of panchromatic and multi-sensor images is used for building footprints extraction. CARTOSAT-1, first Indian Remote sensing satellite capable of providing stereo pair images with aft and fore angles of -5° and 26°, respectively and 2.5 m spatial resolution is used for generating DEM and ortho-rectified images for years 2005 and 2015.

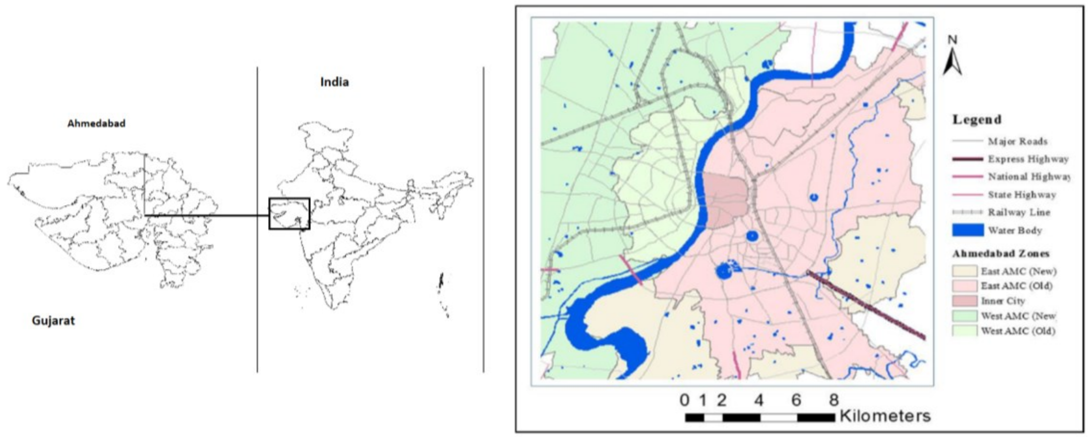

Figure 1: Study area location

Table 1: Specifications of data used

Sr. No.	Satellite	Bands	Spatial Resolution (m)	Date
1.	Cartosat-2	Pan +Multispectral Merged	<1	3/10/2016
3.	Cartosat-1	Stereo pair (Panchromatic)	2.5	24/12/2005
4.	Cartosat-1	Stereo pair (Panchromatic)	2.5	10/10/2015

4. Methodology

4.1 DEM generation

The DEM is generated from Cartosat-1 stereo pairs for year 2005 and 2015 using Leica Photogrammetry Suite (LPS). The DEM was generated with spatial resolution of 5 m. The Rational Function Model (RFM) coefficients, called RPCs, provided along the CARTOSAT data are used in generation of DEM and these are essentially a form of generalized sensor model. These sensor model parameters are terrain independent, have high fitting accuracy and are real time calculated (Tao and Hu, 2002).

4.2 Rational Function Model (RFM)

A sensor model relates 3D object point positions to their corresponding image positions through the collinearity condition. The RFM relates object space coordinates to the image space coordinates. The image pixel coordinates (x, y) are expressed as ratios of polynomials of ground coordinates (X, Y, Z). This method is independent of the sensor resolutions and sensor type and can be used for stereo reconstruction, DEM generation, large scale mapping, ortho-rectification and image registration (Tao, 2001). Generally, they are represented as third order polynomials. Ratios have a forward form as expressed in eq. (1) and eq. (2):

$$x = \frac{P_1(X;Y;Z)}{P_2(X;Y;Z)} \quad (1)$$

$$y = \frac{P_3(X;Y;Z)}{P_4(X;Y;Z)} \quad (2)$$

This equation is called upward RF. Usually, RF model is generated based on a rigorous sensor model. Pi (i =1, 2, 3 and 4) are the polynomial functions**.**

4.3 Data merging

In this study, panchromatic and multi-spectral bands (Red, Green, Blue and NIR) of CARTOSAT-2 are merged to produce the multispectral output with less than one meter using Brovey Transformation. Brovey transformation normalizes the colours of the image, the fused image retains its colour information. The fused image has clear edges, contour which helps to extract feature boundary, texture and ground feature information. (Rong, 2015). The generated image is georeferenced with ortho-rectified image of year 2015. The georeferenced image is used for the classification of building footprint using object based image classification (Figure 2).

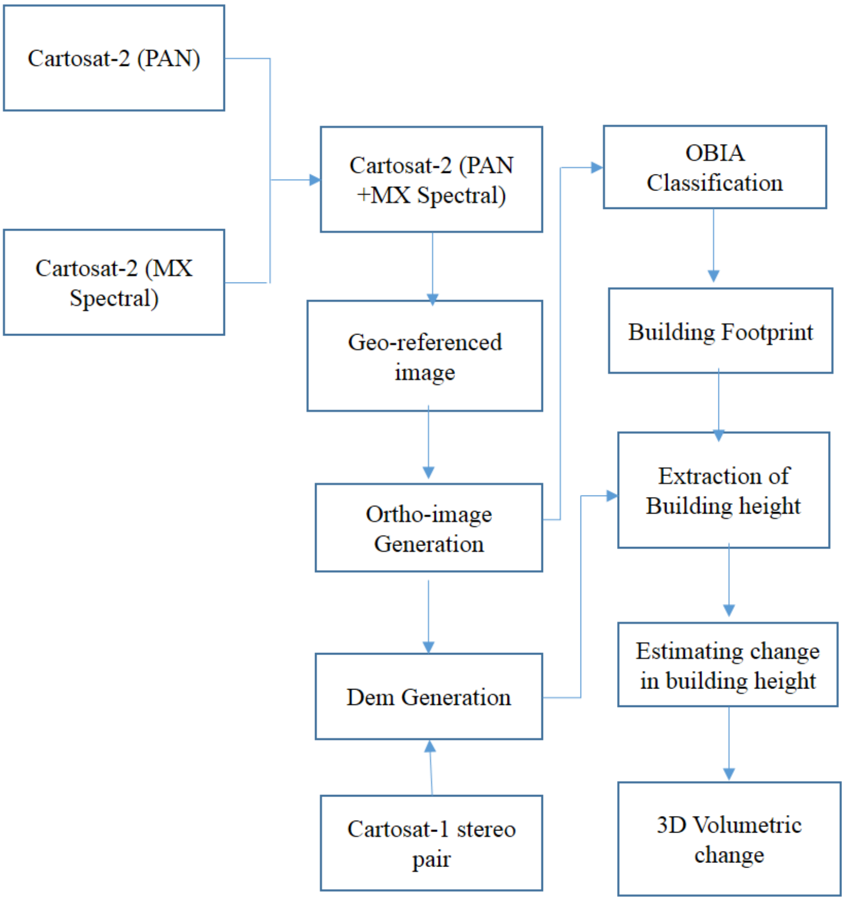

Figure 2: Methodology for volumetric change analysis

4.4 Object based classification

Object based image analysis (OBIA) classifies the images into meaningful group of pixels with homogeneous spectra. The classification of these objects can be done on the bases of its spectral, textural, contextual properties. In object based image classification, instead of classifying the individual pixels. The image is segmented to form image objects. Multi-resolution image segmentation is used to segment the image. This segmentation algorithm consecutively merges the pixels and existing objects. It is a bottom-up algorithm with an optimization approach that for the given number of image objects it minimizes the average heterogeneity and maximizes their respective homogeneity. The scale parameter determines the maximum allowed heterogeneity for the resulting objects. It denotes the size of the object, larger the size of the image object, higher the value of shape parameter. The smoothness and compactness parameter optimizes the resulting image object in regards to smooth borders and overall compactness within shape criteria respectively. For this study, the scale parameter of 15 is used and colour and shape of 0.7 and 0.3, respectively and smoothness and compactness are 0.5 each. Standard nearest neighbour algorithm is used for classify buildings with brightness feature and Gray level co-occurrence matrix (GLCM) homogeneity to classify objects in two types of buildings, i.e. brighter buildings and darker buildings. The mean brightness of an object is computed as in eq. (3):

$$c_k = \frac{1}{s_x \times s_y} \sum_{(x,y)} c(x,y)_k \tag{3}$$

where, c_k is the pixel intensity, s_x number of pixels in the x-direction, s_y number of pixels in the y-direction. The GLCM homogeneity of an object is computed as in eq. (4):

$$H = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \frac{p(i,j)}{1+(i-j)^2} \tag{4}$$

where, $p(i,j)$ is the $(i,j)^{\text{th}}$ entry of the normalized GLCM, as given by eq. (5):

$$p(i,j) = \frac{P(i,j)}{\sum_{i,j} P(i,j)}, \tag{5}$$

where, $P(i,j)$ is the computed GLCM, N_g is the total number of grey levels in the image.

When calculating the GLCM, the pixels within the object are represented in the form of matrix, with pixel value and neighbouring pixel value as coordinates. The value of the matrix is a normalized number of pair occurrences (number of occurrences ÷ number of all pairs). Therefore, GLCM matrix values are always within the range [0, 1]. The GLCM homogeneity measures the smoothness of the grey level distribution of the image and it is inversely correlated with the contrast within the object, smaller the contrast larger the homogeneity within the object. This measure is used since the object contains nearly similar size having interior homogeneity (Flanders et al., 2003).

So, higher value of GLCM indicated the building objects. The objects are then classified to a class using the membership function. (Myint et al., 2011). The membership function determines the feature characteristics, which determines that the image objects belongs to a particular class or not by defining rule sets.

4.5 Building height extraction

The extracted building footprints using object based image analysis is used to evaluate the height information from the stereoscopic CARTOSAT DEM. Building footprints were overlaid on the DEM and the median value of the elevation inside the footprint were extracted using the zonal statistics in the GIS environment by selecting the mean parameter (Figure 3). To estimate the building height, the base value of the bottom of the building is to be computed as shown in figure 4. To compute the lower elevation of the building buffer of 25 m around the building were generated and the minimum value in the buffer is considered as ground elevation. The buffered region is the surrounding area which may represent the ground or surrounding roads or any other ground location representing ground elevation. The difference between the base elevation and average elevation of building represents the height of the building. The building height for 2005 and 2015 were extracted and the change in the height of building is evaluated by subtracting the height obtained from 2015 building footprint to 2005.

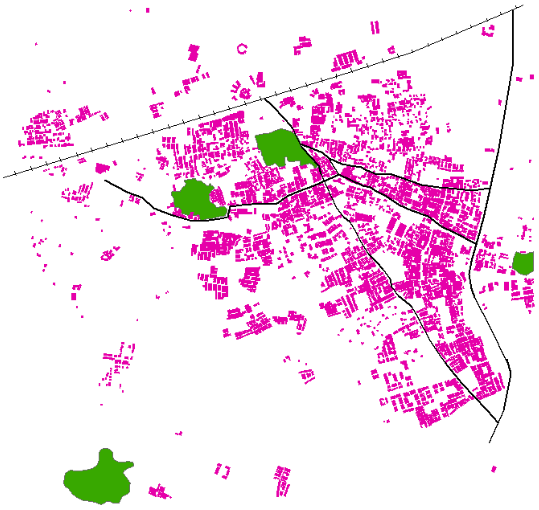

Figure 3: Building footprints extracted

4.6 Accuracy assessment

The accuracy assessment of change in building height was conducted on the sample of 28 randomly selected building in the study area. It was found that most of the buildings heights are identified correctly as shown in figure 6. Since the ground truth is done in 2018, most of the under constructed buildings are fully constructed, so maximum building selected for ground truth were old building and few new buildings. Photographs of two buildings are shown in figure 7.

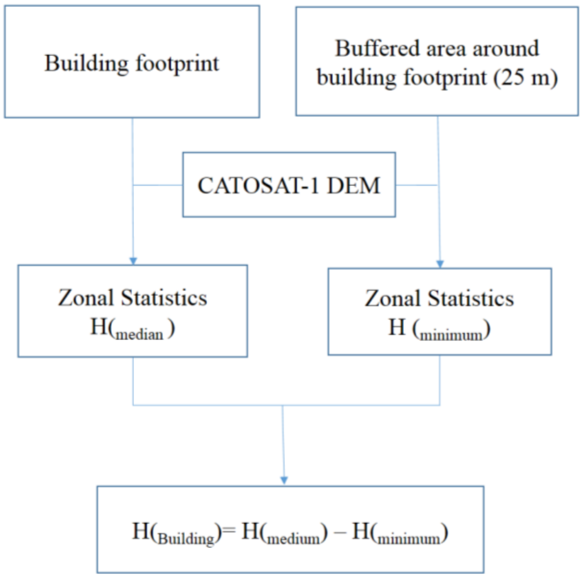

Figure 4: Methodology for building height extraction

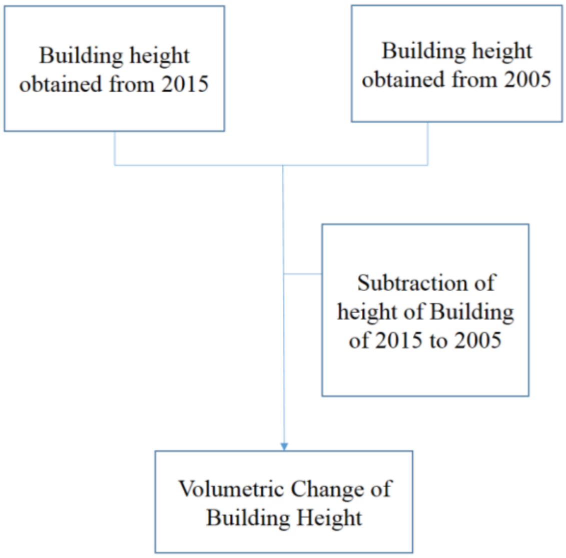

Figure 5: Volumetric change of building from year 2015 to 2005

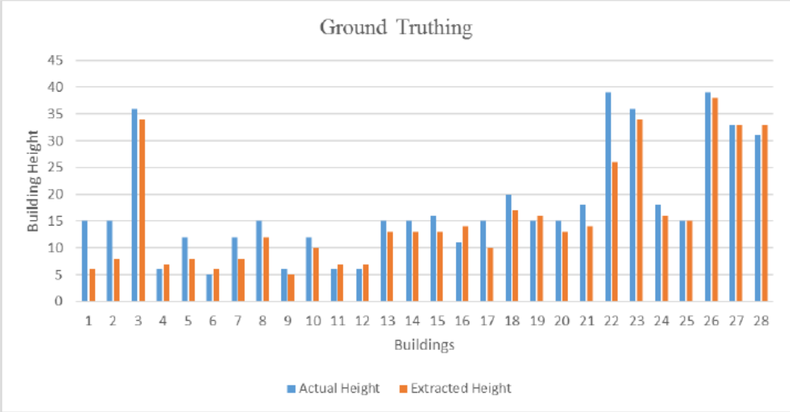

Figure 6: Variations in extracted and actual height

Figure 7: Photographs of buildings

5. Results and discussion

The 3-D volumetric change analysis of study area is carried out using CARTOSAT- 1 stereo pair data and CARTOSAT -2 series data shown in figure 5. The DEM model accuracy of the study area for year 2005 in Easting, Northing and Elevation were observed as 2.61 m, 2.69 m and 1.54 m, respectively. Similarly, the model accuracies for year 2015 were observed as 1.28 m, 0.96 m and 1 m, Easting, Northing and Elevation, respectively. The DEM of 2005 and 2015 year is shown in figure 8. The building foot print were extracted and congested slum area were masked as shown in figure 3. The building elevations were estimated by the median elevation value within the object. The elevation information of the building footprint is added and the building footprint were overlaid on DEMs. The 3-D model of the study area for year 2005 and 2015 is shown in figures 9 and 10, respectively. The volumetric change of urban areas is classified into three types: new construction, reconstruction and unchanged built-up area. The volumetric change in percentage for new construction, reconstruction and unchanged built-up area are 18.3, 7.8 and 73.9, respectively. The built-up areas change and volume change are shown in table 2. The volumetric change for buildings with heights less than 5 m, between 5-10 m, 10-20 m and 20-30 m and buildings with height more than 30 m is evaluated. There is volumetric change of 4.75% for buildings less than 5 m in height, 28.52% for 5-10 m, 60.5% for 10-20 m and 5.2% for 20-30 m and 1.72% for buildings with 30 m and above as shown in Table 3. The maximum volumetric change is observed in buildings with height between 10-20 m, this indicates that the highest development of medium rise buildings took place from 2005 to 2015. These buildings could be residential houses such as bungalows, apartments and educational institutes. Since the development of high rise buildings is observed in past few years, resulting the growth of buildings in vertical direction. The 2-D urban built-up change analysis can only infer the land use/ land cover change, but it limits the capability for analysing the high rise buildings. Since, 2-D mapping of urban area infers only about the area occupied by the urban built-up but 3-D model gives the additional information of the number of floors. The floor-wise information can further help for evaluating the floor area ratio (FAR). Higher the value of FAR, denser the area to live in sharing the common resources such as electricity, water supply, elevators, etc. The resource allocation problem can be solved through this information.

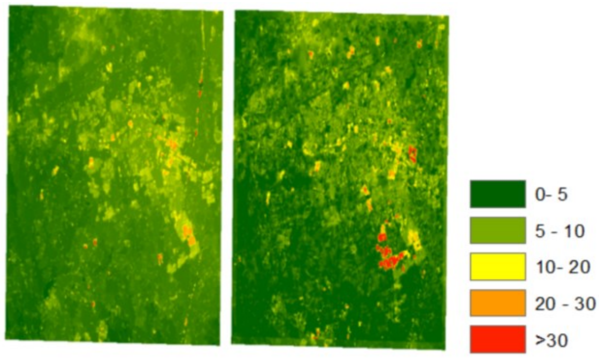

Figure 8: DEM for year (a) 2005 and (b) 2015

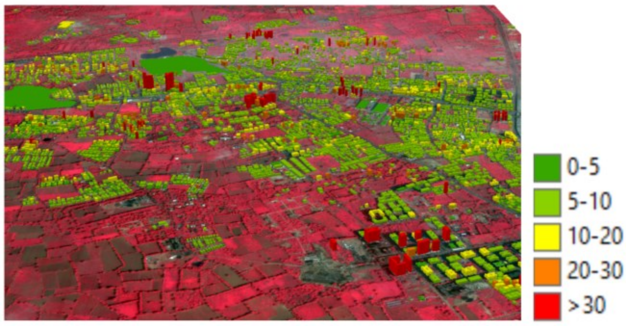

Figure 9: Building height extracted for 2005

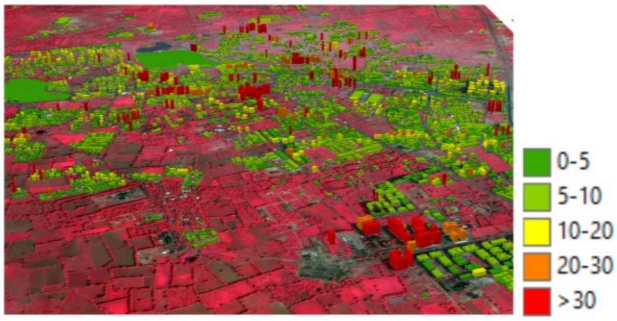

Figure 10: Building height extracted for 2015

Table 2: Built-up area change and volume change from 2005 to 2015

Building Type	**Area change (hectare)**	**Area change (%)**	**Volume Change (%)**
Newly constructed Building area	47.35	10	18.3
Reconstructed Building Area	21.17	4.47	7.8
Unchanged Building Area	405.05	85.53	73.9

Table 3: Volumetric change as per building height from 2005 to 2015

Building Type (Height in meter)	**Volume Change (%)**
<5	4.75
5-10	28.52
10-20	60.5
20-30	5.2
>30	1.72

6. Conclusions

This study highlights the significance of 3D model generation employing photogrammetric techniques. Building footprint were extracted using object based semi-automatic techniques, using the merged product of very high resolution satellite imagery. Through this study the volumetric change in urban areas is calculated in one decade from 2005 to 2015.The significant development of medium rise buildings were observed. Since the development of high rise buildings is observed in past few years, resulting of growth of buildings in vertical direction. The 2-D urban built-up change analysis can only infer the land use/ land cover change, but it limits the capability for analysing the high rise buildings. The study for urban built-up in 2-D is not sufficient for solving the urban modelling, with problems related to resource allocation. In future, the study of volumetric change analysis using FAR is planned to conduct for resource allocation problem.

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References

Flanders, D., M. Hall-Beyer and J. Pereverzoff (2003). Preliminary evaluation of eCognition object-based software for cut block delineation and feature extraction. Canadian Journal of Remote Sensing, 29(4), 441–452.

Haralick, R.M., K. Shanmugan and I. Dinstein (1973). Textural Features for Image Classification. IEEE Transactions on Systems, Man and Cybernetics, SMC-3(6), 610–621.

Kolbe, T. H., G. Gröger and L. Plümer (2005). CityGML-Interoperable Access to 3D City Models. International Symposium on Geo-Informationon Disaster Management, Delft, the Netherlands, Springer.

Myint, S. W., P. Gober, A. Brazel, S. Grossman-Clarke and Q. Weng (2011). Per-pixel vs. object-based classification of urban land coverextraction using high spatial resolution imagery. Remote Sensing of Environment doi:10.1016/j.rse.2010.12.017.

Rong, C. (2015). The analysis of image fusion on improved Brovery Transform. International Industrial

Informatics and Computer Engineering Conference (IIICEC)

Sharma, S.A., R. Agrawal and P. Jayaprasad (2016). Indian Soc. Remote Sens. 44:187 https://doi.org/10.10007/s12524-015-0478-9

Tao, C. V. and Y. Hu (2002). Updating solutions of the Rational Function Model using additional control information. Photogrammetric Engineering & Remote Sensing, 68(7), 715–723.

Tao, C.V. (2001). A Comprehensive Study of the Rational Function Model for Photogrammetric Processing, PE&RS 67 (12), 1347-1357. http://www.geoict.yorku.ca/project/rationalmapper/pers2001_rfm.pdf