COMPARATIVE EVALUATION OF PLEIADES, CARTOSAT- 2 AND KOMPSAT-3 STEREO DATA FOR DSM AND 3D MODEL GENERATION

Kshama Gupta*[1], Pushplata[2], Sandeep John[3], Ashutosh Bhardwaj[1], Pramod Kumar[1], A. Senthil Kumar[1]

[1]Indian Institute of Remote Sensing, 4, Kalidas Road, Dehradun
[2] Indian Institute of Technology, Roorkee
[3]School of Spatial IT, IST, JNTUK, Kakinada
*Corresponding Author, email: kshama@iirs.gov.in

ABSTRACT

Growing urbanization in horizontal as well as vertical direction demands modeling and monitoring of urban areas in 2D as well as 3D. Although, LiDAR and airborne image data are considered as standout amongst other datasets for the extraction of 3D models of urban areas, but they have limited availability. On the other hand, increasing availability of sub-meter resolution satellite stereo datasets have opened up new vistas and potentials in this field. Since, satellite images have wider coverage and less restrictions for use, they are explored world-wide for the extraction of 3D parameters. Hence, in this study, a comparative evaluation of Cartosat-2, Kompsat-3 and Pleiades stereo datasets was carried out for the Digital Surface Model (DSM), normalized DSM (nDSM), Ortho and 3D model generation for an urban area. The DSM was generated both using RPC model and by integrating the Ground Control Points (GCPs) obtained from DGPS survey for evaluation purpose. It was found that the accuracy of DSM generated using GCPs have improved significantly for Cartosat-2 and Kompsat-3. The accuracy of DSM generated using RPC model of Pleiades was found to be 0.20 m in X, 0.18 m in Y and 1.33 m in Z direction. The RMS error of the nDSM was found to be 0.31 m for Pleiades data and 4.1 m for Kompsat-3 data.

KEYWORDS: High Resolution stereo, 3 D model, Building Heights, DSM

1.0 INTRODUCTION

Stadler & Kolbe (2007) define 3D city models as digital representation of the Earth's surface and its related objects belonging to the urban areas such as building, tree, vegetation, and manmade features. Although, LiDAR is considered as one of the best technology for 3D urban surface modeling (Rottensteiner and Jansa, 2002), however, its limited availability and data cost, limits its use. On the other hand, increasing availability of high resolution stereo data opens new potentials for effective utilization of these datasets for Digital Surface Models (DSM) and 3D modeling applications. During last decade, high resolution satellite data has been explored extensively for 3D modeling and DSM generation in urban areas. The availability of good quality high resolution satellite stereo imagery can be applied not only for 2D urban feature extraction but also the extraction of 3D or height information and for effective 3D visualization of urban areas. High resolution satellite images such as Pleiades, IKONOS, Cartosat and Quick Bird also provide the high temporal resolution to overcome the aerial image limitation (Ibrahim et al., 2011). Thomas et al. (2003) concluded that high-resolution imagery is a valuable tool for mapping urban areas and extracting land cover information. The high resolution satellite imagery have been used by many researchers worldwide for 3D city model generation and urban features extraction using automatic and semi-automatic methods (Armin et al., 2003; Kocaman et al., 2006; Koc-San et al., 2010; Mahmoud et al., 2012; Gupta et al., 2015).

Pleiades sensor differ from other high resolution satellites such as Ikonos, Geo-eye, Kompsat, Cartosat-2, which acquire stereo in subsequent passes. The Pleiades constellation consists of two identical satellites Pleiades-1A and Pleiades-1B, which have been launched in December 2011 and December 2012, respectively. Both satellites have outstanding agility, as pointing angles are in the range of ±47 degrees. Both satellites are equipped with tri-stereo capabilities i.e., they have three cameras on-board for acquiring images in nadir, forward and backward direction in a single-pass along with high spatial resolution of 0.5 m, makes this data an ideal dataset for 3D modeling of city and high relief areas (Perko et al., 2014). Kompsat-3 is a Korean satellite launched on 19 May 2012. It provides panchromatic optical images at a spatial resolution of 70 cm and can be utilized for urban 3D applications. The satellite has pass around 1:30 PM which reduces the amount of shadow in the image, which is considered ideal for urban area mapping (Jeong et al., 2016). The Cartosat-2 data is provided with Indian remote sensing cartosat series satellites with a GSD of 1 m. Although, it is a mono data, the stereo data can be procured from subsequent pass data. Hence, in this study, a comparative evaluation of Pleiades, Kompsat-3 and Cartosat-2 data was carried out for DSM generation and 3D model generation for a part of Delhi National Capital Region (NCR).

2.0 STUDY AREA AND DATA USED

Delhi is the national capital of India as well as a fast growing metropolitan area, located at 28.61°N and 77.23°E, and lies in northern India. It borders the Indian states of Haryana on the north, west and south, and Uttar Pradesh (UP) to the east. Two prominent features of the geography of Delhi are the Yamuna flood plains and the Delhi ridge. Being the national Capital, Delhi NCR region is a seat of large number of Government offices and even private service sector. Delhi and NCR region have grown tremendously over a period of time and attracted high amount of population from far flung areas of India. During the last decade, an upsurge of multistoried high-rise building structures is seen in Delhi and its surroundings NCR region to accommodate the ever increasing population. Pleiades and Cartosat-2 stereo pairs for parts of Delhi NCR were procured from NRSC, Hyderabad and a sample data of Kompsat-3 was made available by NRSC, Hyderabad for the similar area (Figure 1).

Table 1: Details of Data used

S. No.	Satellite/ Sensor	Date of acquisition	Resolution (m)	View(Roll) Angles (Degrees)
1.	Cartosat-2	25MAR 2011	1m	-7.834
2.	Cartosat-2	30MAR 2011	1m	14.993
3.	Cartosat-2	14MAY 2010	1m	-14.304
4.	Kompsat-3	23 MAY 2013	1m (0.7)*	19.01
5.	Kompsat-3	05 Jan 2015	1m (0.7)*	0.50
6.	Pleiades 1A	22 Jun 2013	0.5	9.61
7.	Pleiades 1A	22 Jun 2013	0.5	14.33

**Kompsat-3 data is acquired at 0.7 m resolution.*

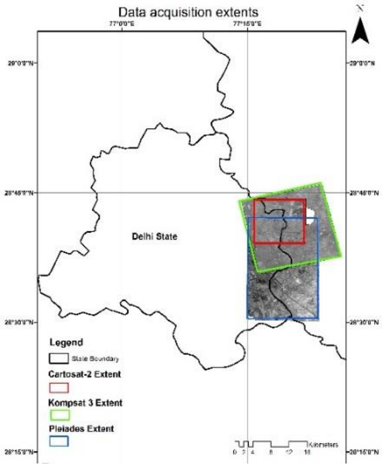


Figure 1: Extent of Stereo Pairs

3.0 METHODS

This section presents the analytical approaches followed to process and evaluate the datasets for DSM generation and 3D model extraction. The methodology used is presented in Figure 2 and the details of each step is presented in following sections.

3.1 DGPS survey for collection of ground control points

A Differential Ground Positioning System (DGPS) survey was carried out in the study area to collect the Ground Control Points (GCPs) for accurate registration and accuracy assessment. 25 well-distributed points were collected and care was taken for the even distribution of GCPs in the study area. Minimum 60 minutes observations were obtained at each rover station and base was operated continuously for 4 days i.e. approx. 106 hours. The collected GCPs were used for assessing the accuracy of generated DSM with RPC model as well as after processing with GCPs. 15 GCPS were used for DSM generation while others were used for accuracy assessment.

3.2 Photogrammetric pre-processing

One of the first steps in photogrammetric preprocessing is reconstructing the sensor model in photogrammetric software. Images were oriented with Rational Polynomial Coefficients (RPCs) in the photogrammetry block to process the stereo pairs without the need for Ground Control Points (GCP). These coefficients are also used to specify the geometric model, which defines the internal characteristics (i.e. internal geometry of the camera or sensor while capturing the imagery) and external parameters (i.e. original position and orientation of the camera or sensor). To extract DSM, a block model is built up with stereo image in photogrammetric software. Further, automatic tie point generation is carried out to measure the corresponding image positions of tie points on overlapping images.

3.3 Block triangulation

Block triangulation is the process of defining the mathematical relationship between the images contained within a project, the camera or sensor model that obtained the images, and the ground. Once the relationship has been defined, accurate and intelligent imagery and information concerning the Earth's surface was created. After the identification of automatic tie points based on RPC model, block triangulation was carried out and the RMSE of less than 1 pixel was achieved. Further, GCPs obtained from ground were integrated in the block and again the block triangulation was carried out. The block was adjusted and RMSE of less than 1 pixel was achieved.

3.4 DSM and ortho-image generation with RPC model and ground control points

A digital surface model represents the elevation associated with the surface of the earth including topography and all natural or human-made features located on the surface of the earth. Using automatic extraction of DSM module in Photogrammetric software, the DSM for each stereo pair was generated. After the integration of GCPs in the block and adjustment of block, again the DSM was generated by using automatic extraction module for each stereo dataset. DSM generated in each step was further used to generate the ortho-image from each stereo dataset. The generated ortho-image was analyzed visually.

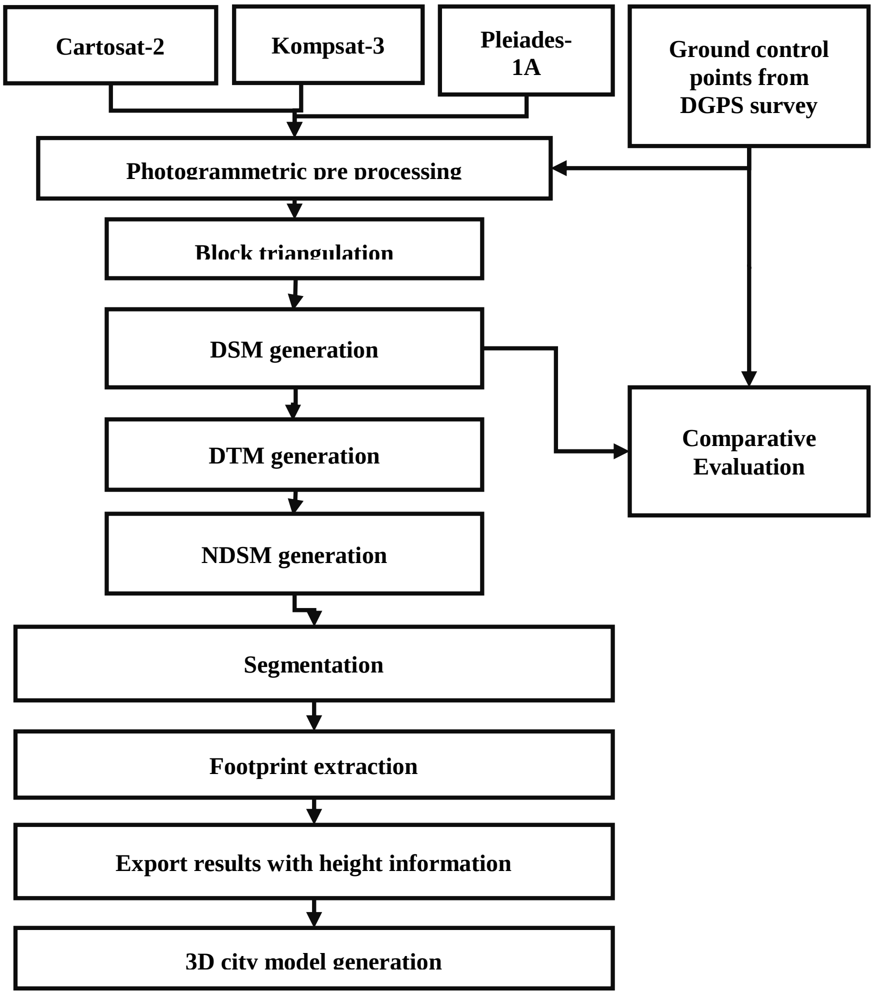


Figure 2: Flow diagram of Methodology

3.5 Digital Terrain Model (DTM) generation

A digital terrain model is a topographic model of the bare earth (terrain relief) that can be manipulated by computer programs. The data files contain spatial elevation data of the terrain in a digital format which is usually presented as a rectangular grid. The vegetation, buildings and other man-made features are removed (relieved) by applying filters, leaving just the underlying terrain.

3.6 nDSM generation

Normalized DSM (nDSM) represents the height of all the objects present on the terrain. It is generated by pixel-by-pixel difference between DSM and DTM using a characteristics equation given as, nDSM = DSM-DTM. The null value was assigned to the features that are not much useful such as vegetation, roads in GIS software.

3.7 Segmentation and Classification

nDSM was used for footprint extraction by applying multi-resolution segmentation algorithm, which merges the pixels of same shape and size based on homogeneity criteria. Three distinct criteria viz. scale, shape and compactness were used to optimize the image objects. Then, assigning class algorithm is used to classify the objects based on threshold with mean value (brightness).

3.8 Generation of 3D city model

The classified building footprint image was exported to shapefile including brightness value as height information in attribute and further processed in GIS environment for extruding the 3D building.

3.9 Accuracy Assessment and Comparative Evaluation

The DSMs generated from RPC model and after adjustment with GCPs were evaluated with respect to other sets of GCPs obtained from ground. The mean, Root Mean Square (RMS) error and standard deviation was calculated to define the accuracy parameters. Further, nDSM generated was also evaluated with reference to the building heights obtained from ground measurements using Laser distance meter.

4.0 RESULTS

4.1 DSM and Ortho Processing

Initially, all three data sets were processed based on RPC model in photogrammetric software and then further processed by ingesting the GCPs obtained from ground by DGPS survey. The obtained GCPS were then used for block adjustment and then further processing of DSM. In case of Cartosat-2, few GCPs were obtained from adjusted Kompsat-3 Block. After block adjustment and triangulation, RMSE for each block was 0.26, 0.55 and 0.14 pixels for Cartosat-2, Kompsat-3 and Pleaides blocks, respectively.

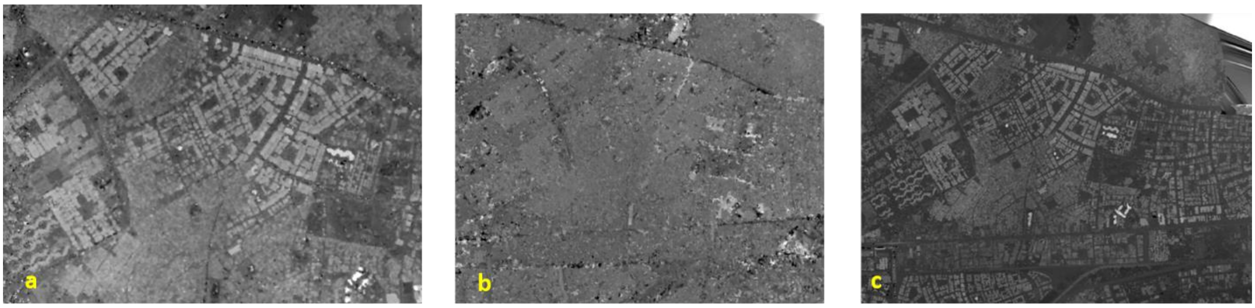
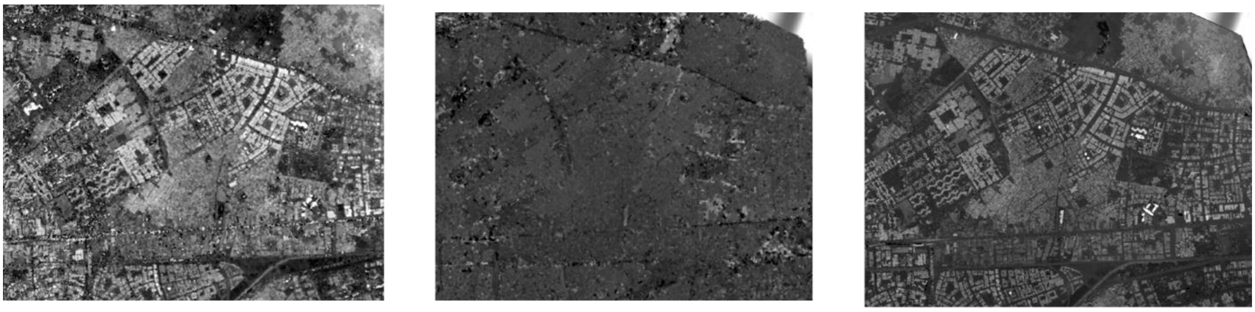


Figure 3: Zoomed view of DSMs generated using RPC model a. Cartosat-2 b. Kompsat-3 c. Pleiades



Cartosat-2 Kompsat-3 Pleiades

Figure 4: Zoomed view of DSM generated using GCPs from DGPS survey

Table 2: Comparative evaluation of all three datasets with respect to GCPs from Ground

Sensor/Data	RPC Model			GCPs from DGPS survey		
	X-reference (m)	Y-reference (m)	Z-elevation (m)	X-reference (m)	Y-reference (m)	Z-elevation (m)
Pleiades						
Average	0.17	0.24	5.44	0.04	0.31	1.78
RMSE	0.42	0.49	2.33 m	0.20	0.18	1.33
Std. Dev.	0.22	0.14	0.67	0.12	0.08	0.31
Cartosat-2						
Average	52.5	75.21	112.1	1.99	0.77	2.00
RMSE	22.91	27.42	33.48	1.41	0.88	4.47
Std. Dev.	8.75	8.92	3.42	0.99	0.86	0.21
Kompsat 3						
Average	44.31	51.11	33.38	0.31	1.63	25.69
RMSE	6.66	71.49	57.78	0.56	1.28	5.07
Std. Dev.	2.78	8.84	6.01	0.52	0.88	1.03

The zoomed view of DSMs generated from RPC model is presented in Figure 3 and DSMs generated using block with GCPs is presented in Figure 4. It is to be noted that visual quality of DSM generated from Cartosat-2 and Pleiades data sets are comparable, however, the visual quality of DSM generated from Kompsat-3 data is quite poor due to poor contrast in the specific scene. The evaluation of all DSMs were carried out using GCPs which were not used for adjusting the block. The results of the evaluation are presented in Table 2. Pleiades data provided good accuracies (less than a pixel in x and y) with the RPC model, although, improvement in accuracies in x. y and z is seen after the use of GCPs from DGPS survey (Table 2). However, it is evident from the Table 2 that significant improvement is seen in the accuracies of Cartosat-2 and Kompsat-3 (meters to sub-meter accuracy in x and y) in all the directions after the use of GCPs from DGPS survey. In terms of z- value, Cartosat-2 is giving better results than Kompsat-3.

4.2 3D Modeling and Building Footprint Extraction

Preliminary results are presented here with respect to 3D modeling and automatic extraction of building footprint from Pleiades and Kompsat-3. The extraction of building footprints and heights from Pleiades data are comparatively better than Kompsat-3 and Cartosat-2 data. The height was also obtained during segmentation

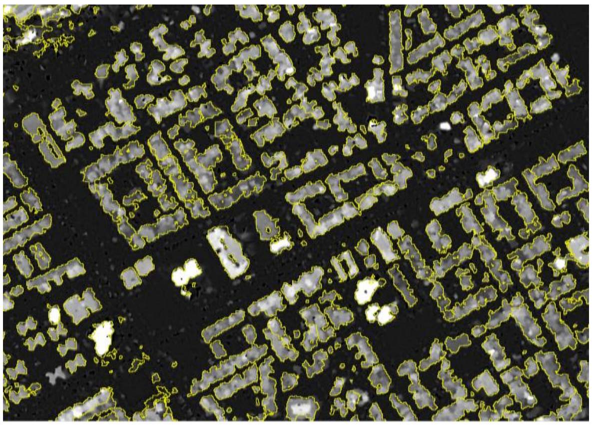


Figure 5: Building Footprint extracted from Pleiades data overlaid on Pleiades nDSM, Part of Delhi NCR

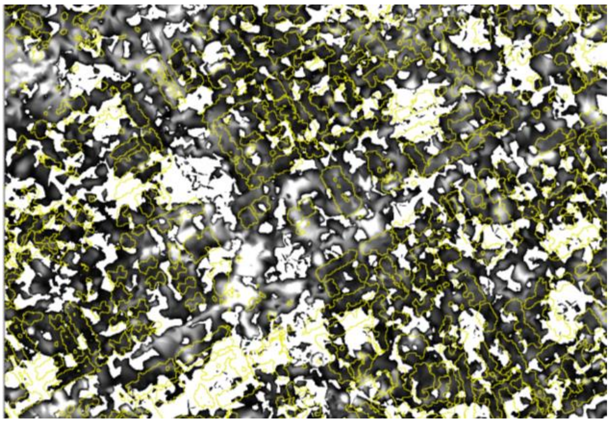


Figure 6: Building Footprint extracted from Pleaides data overlaid on Kompsat-3 nDSM, Part of Delhi NCR

process. The building height thus extracted automatically was compared with heights obtained from ground survey. The RMSE was found to be 0.31 m for Pleiades data and 4.1 m in case of Kompsat-3 data. However, further assessment in terms of different height groups will be carried out in future. Figure 5 presents zoomed view of extracted footprints from Pleiades data overlaid over Pleiades nDSM and Figure 6 presents zoomed view of

Figure 7: Building Footprint extracted from Pleiades data overlaid on Pleiades Ortho, Part of Delhi NCR

Figure 8: Building Footprint extracted from Pleaides data overlaid on Kompsat-3 Ortho, Part of Delhi NCR

extracted footprints from Pleiades data overlaid over Kompsat-3 nDSM for similar area. It is clear that Kompsat-3 DSM and nDSM has high amount of noise and building outlines are not clear. Similarly, figure 7 presents extracted building footprints overlaid on Pleiades ortho and Figure 8 presents extracted building footprints overlaid on Kompsat-3 ortho. Figure 9 presents 3D view of extracted footprints from Pleiades data and Figure 10 presents the 3D view of extracted footprints from Kompsat-3 data. The building footprint extraction results needs further investigation and improvement in segmentation methods.

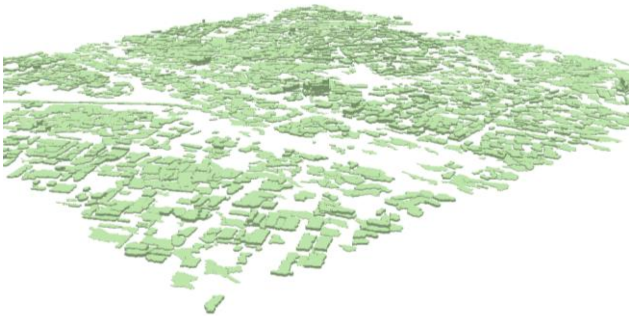


Figure 9: 3D view of Building Footprint extracted (Pleiades Data), Part of Delhi NCR

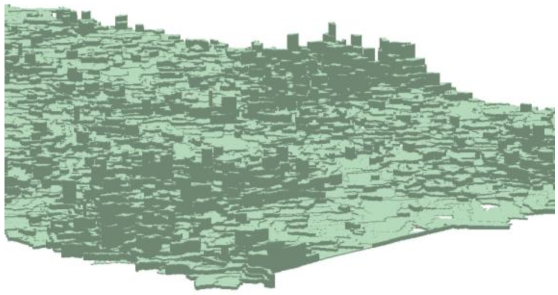


Figure 10: 3D view of Building Footprint extracted (Kompsat-3 Data), Part of Delhi NCR

5.0 CONCLUSION

Host of high resolution sub-meter satellite stereo datasets are now available which are explored for extraction of 3D parameters for urban areas. In this study, a comparative evaluation of Cartosat-2, Kompsat-3 and Pleiades data was carried out for DSM, nDSM, Ortho and 3D model generation. The DSM for each dataset was generated using RPC model as well as GCPs from DGPS survey. The accuracy of DSMs generated were evaluated from both the sources with respect to GCPs obtained from ground. The separate set of GCPs were used for evaluation as well as for adjustment of photogrammetric block. The RMSE of Cartosat-2 and Kompsat-3 data with RPC model was found to be 22.91 m and 6.66 m in X, 27.42 m and 71.49 m in Y and 33.48 m and 57.78 m in Z, respectively. However, the accuracy of DSM generated using Pleaides data and RPC model was found to be of the order of sub-meter accuracy i.e. 0.42 m and 0.49 m in X and Y directions, respectively and 2.33 m in Z direction. Hence, it was noted that for the applications which require meter level planimetric accuracy, Pleaides data may be used by applying the RPC model. The accuracy of Cartosat-2 and Kompsat-3 data have been improved significantly after the induction of GCPs in photogrammetric block. The RMSE error have been reduced to near 1 m in X and Y direction but in Z direction it was near to 5 m. The nDSM obtained from Pleiades and Kompsat-3 was also evaluated with reference to ground measurements and RMS error was found to be 0.31m for Pleiades and 4.1 m for Kompsat-3 data. However, further investigation on other sample areas and improvement in segmentation methods is required for improved results.

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