Estimation of Height of Building Using High Resolution Satellite Image

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Keywords: K-Means Algorithm, Building Shadow Width, Sun-Satellite Geometry Method, Bounding Rectangle.

Abstract: Buildings along with their properties such as, shape, rooftop reflectance, structure, etc. are one of the most commonly observed structures in urban areas. Two-dimensional (2D) building footprint along with building height information play an important role in the field of urban development, urban planning, population estimation, map making, disaster management, and various other socioeconomic applications. Shadow cast by buildings plays a vital role in estimation of height of building. In this study, sun-satellite geometry method using shadow cast by building has been used to estimate height of building. However, accurate shadow detection, extraction, and measuring width of the shadow zone are some of the important aspects in estimation of height of building. In order to detect and extract width of the shadow zone accurately, OBIA has been used. Further, accuracy in measuring width of the shadow zone has been improved by introducing a new algorithm and considering sun illumination direction and orientation of building. OBIA along with new algorithm to measure width of the shadow zone provides a sound methodology for estimation of height of all types and shape of buildings.

1 INTRODUCTION

Earth observation satellite images provides very important information about earth surface and play a vital role in various remote sensing applications like change detection, disaster management, urban planning, Land Use Land Cover (LULC) mapping and many other socio-economic happenings. In addition, multispectral characteristics of satellite images further helps to improve feature recognition and LULC mapping. Applications such as, feature recognition has considerably increased since High Resolution Satellite (HRS) images from QUICKBIRD, IKONOS, RapidEye, WorldView, etc. have been made available for research and development. Especially, HRS images found its applications in various urban applications wherein they play an important role to identify and extract various urban related features such as, buildings, trees, roads, and other natural or manmade features.

Buildings having different structure, shape, and rooftop reflectance are one of the most commonly observed structures in urban regions. In various applications such as, urban planning, urban development, land use analysis, map making, climate studies, change detection, and disaster management two-dimensional building footprints (2D) and three-dimensional building models (3D) provide an important information (Sırmaçek and Ünsalan, 2008; Sırmaçek and Ünsalan, 2011; Gavankar & Ghosh, 2018).

Estimation of height of a building is an important application of urban remote sensing using HRS data. Height of a building may be estimated from remotely sensed data by using different types of data sources, such as, HRS image, Synthetic Aperture Radar (SAR), Light Detection and Ranging (LIDAR) point

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Gavankar, N., Rathod, R. and Waghmare, V.
Estimation of Height of Building Using High Resolution Satellite Image.
DOI: 10.5220/0012731600003696

In *Proceedings of the 10th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2024)*, pages 83-93
ISBN: 978-989-758-694-1; ISSN: 2184-500X

cloud, Digital Elevation Model (DEM), and Digital Surface Model (DSM).

Building height information using remote sensing data may be extracted by investigating the effect of building on surroundings, such as, by measuring width of shadow cast by a building (Massalabi et al., 2004). In order to estimate height of building from shadow, accurate detection, extraction, and measuring shadow length are some of the important yet challenging steps. However, extent of shadow visible in satellite image is entirely depends on the position of sun and satellite at the time of acquisition of image. A typical view of sun-satellite geometry formed with respect to building and shadow cast by a building is shown in Fig. 1. Further, height of a building may be calculated by deriving a suitable trigonometric relation, considering sun-satellite-building geometry formed.

In Fig. 1, S is the width of shadow cast by the building, ω is altitude of sun and θ is altitude of satellite.

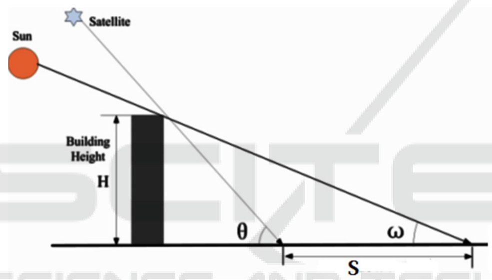


Figure 1: The relationship of the sun, satellite and building at the time of image acquisition (Wang et al., 2014).

In order to estimate height of building from single HRS image, sun-satellite geometry method has been widely used in various studies. However, methodology for measuring width of shadow cast by building, a crucial step during estimation of height of building, has been largely neglected. In some studies, Bounding Rectangle (box) method has been used to measure the width of shadow zone to estimate height of the building (Shettigara & Sumerling, 1998; Raju et al., 2014) yet it is suitable for regular shape buildings. Further, it has been observed that Bounding Box method used to measure shadow length, gives large error during estimation of height in case of irregular shape buildings. Also sun illumination, its direction and orientation of building plays a key role in shadow cast by irregular shape building, has not been considered. Some of the challenges in estimation of height of building from HRS image are as given below:

i) Require suitable technique to extract shadow precisely from HRS image.

ii) Slight error in measuring width of shadow cast by building may cause large error in estimation of height of building.

iii) Development of suitable relationship to determine height of building considering sun-satellite geometry at the time of image acquisition.

In order to provide common solution to estimate height of all types of buildings, there is need for an improved or a new technique. A new technique should ideally be able to extract shadow precisely from HRS image, provide reliable shadow width measuring technique, and provide suitable relation (equation) to represent sun-satellite geometry formed at the time of image acquisition, in order to estimate height of a building.

The main objective of this study is to estimate height of different types/shapes of buildings from shadow cast by a building using HRS multispectral image.

2 LITERATURE REVIEW

Extraction of building footprints from satellite images has been a difficult task due to their different structural and spectral properties. In different studies, various automatic and semi-automatic techniques for extraction of building footprints from remotely sensed image have been discussed. Similarly, large number of studies has been carried out for estimation of height of building by different researchers. The objective of this section is to present a detailed review of different techniques for extraction of shadow of buildings and methods for estimating the height of building using High Resolution satellite (HRS) image/images.

Satellite images provide valuable information about the ground. One such application is extraction of building and estimation of building height from satellite image. This information may be important aspect for urban remote sensing, such as, urban change detection, natural disaster monitoring, preparing and updating building inventory database, taxation, etc. In literature, many studies have been carried out using Synthetic Aperture Radar (SAR) images (Guillaso et al., 2005; Guida et al., 2010; Brunner et al., 2010) or from fused of SAR and high resolution optical images (Sportouche et al., 2011). Since, building height information using optical remote sensing data may be extracted by investigating the effect of building on the surroundings, such as, by measuring shadow cast by the building (Massalabi et al., 2004). Although, shadows have been considered as noise in many remote sensing applications, shadow cast by a building plays a vital role in estimation of building height. In order to estimate building height from shadow, accurate detection, extraction, and measurement of shadow width are some of the important and challenging steps. During estimating of height of building using shadow width, a key assumption has been made that the surface on which shadow fall is flat surface and that the shadow cast by building does not fall on another building.

In general, shadow extraction from satellite imagery has been a fundamental step in estimation of building height. Various studies have been carried out in order extract shadow from satellite imagery (Sarabandi et al., 2004; Arévalo et al., 2008; Liu and Yamazaki, 2012; Song et al., 2014). Subsequently, this information have been used in various applications, such as, detection of buildings (Chen et al., 2014), estimation of height of building (Raju et al, 2014; Shao et al., 2011), removal of shadow (Dare, 2005; Guo et al., 2010), etc.

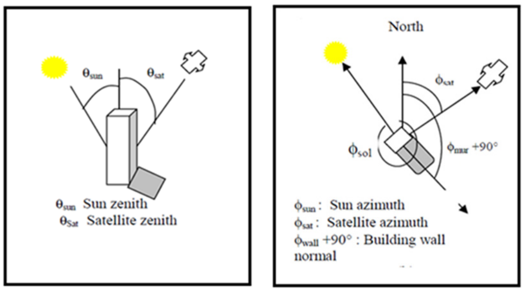
Cheng and Thiel (1995) estimated height of a building from shadow width using SPOT panchromatic image. Experimentation has been carried out on a 42 high-rise building and result shows a Root-Mean-Square (RMSE) error of 3.69 m in height estimation. In another study carried out by Hartl and Cheng, (1995) reported 6.13m RMSE error in height estimation for 77 buildings in the study area.

Shettigara and Sumerling (1998) introduced a sun-sensor-shadow geometry method, later referred as sun-satellite geometry method, to estimate height of building using shadow width. In order to calculate height of building (h_t), Eq. 1 has been derived by using sun-satellite geometry at the time of imaging. The early attainment of the proposed methodology has been the accuracy obtained, which is nearly one third of the size of panchromatic pixel. However, the limitation of the proposed technique is applicable for estimating height of only extended objects situated on flat terrain.

$$h_t = S / \{[cos(\phi_{sun})\ tan(\theta_{su})] - [cos(\phi_{san}) \tan(\theta_{sa})]\} \quad (1)$$

where, S is the shadow width (area of the shadow zone divided by the width of the zone), ϕ_{sun}, ϕ_{sa} are the azimuth angle of sun and satellite, and θ_{su}, θ_{sa} are the elevation of sun and satellite respectively.

The concept of sun-satellite geometry method has been further explained in detail by Massalabi et al., (2004), with the help of perspective view and plane view, (Fig. 2). Estimation of building height from shadow width depends on several parameters, such as, sun elevation angle, sun azimuth angle, relative position of the sun, shadow of the object, and sensor. Here, sun azimuth and elevation angle determines the orientation of shadow, while their relative position determines the proportion and component of shadow viewed by the sensor.



(a) Perspective view (b) Plane view

Figure 2: Position of sun, building, and satellite with respective to North at the time of image acquisition (Massalabi et al., 2004).

Wang and Wang (2009) proposed a methodology to extract information of buildings along with density of buildings in Kunming, China using QuickBird imagery. During experimentation, calculation of height of building has been carried out on the basis of hypothesis made and sun-satellite geometry formed at the time of imaging. In order to estimate height of building, sun and satellite elevation and azimuth angle is required and these are available in the metadata file available with satellite data. The results obtained suggest that with increase in height of building, error in height estimation reduces. Further, results obtained show that height of building calculated from shadow and height investigated on sites, forms a linear relationship, represented by the following equation.

$$H_t = \alpha H_x + \beta \quad (2)$$

where, H_t and H_x are the height calculated from shadow and investigated height respectively, α and β are the coefficient of formula.

Shao et al. (2011) presented a simple sun-building shadow relationship model for estimating height of high-rise buildings from IKONOS image for a part of Bangkok city. In order to delineate shadows of high rise buildings from low and connected building shadows, proposed methodology uses object shape index. The object shape index has been obtained by calculating a ratio of perimeter of shadow to the area of shadow. Further, width of the shadow object has been measured in the direction of sun azimuth angle and height of building has been calculated using following sun-building shadow relationship.

$$H = L \times \tan(\Theta) \quad (3)$$

where, H is the height of the building, L is the width of shadow, and Θ is the sun elevation angle. Results show that less than 8m error has been reported for nearly 62% of buildings.

Liasis and Stavrou (2016) used a similar sun-building shadow relationship and estimated height of building using Eq. 3. Further, the aggregate variance (error) reported in estimating height of building have been 4.13%, which includes buildings of all categories, such as, office, residential, and their combination.

A rule-based approach has been presented by Comber et al., (2012) in order to estimate height of building from ALOS data, using shadow width. Initially, segmentation have been carried out using parameters, such as, scale, shape, and compactness. Thereafter, classification has been performed using rule-based approach. Further, rules have been defined to allocate shadow objects to different building classes, which have been used in conjunction with geo-located photographs. The defined rules have been derived on the basis of spatial properties, width and shape of the shadow objects, along with their adjacency to building. Thereafter, height of building (H) has been calculated using following equation:

$$H = \frac{W}{\frac{\cos(\varphi_{\mathrm{sun}} + 90 + \varphi_{\mathrm{az}})}{\tan(\varphi \mathrm{sun})}} \quad (4)$$

where, W is the shadow width, φ_{sun} and φ_{az} are the sun angle and sun azimuth angle respectively. However, during estimation of building height, satellite azimuth and elevation angles have been ignored.

Lee and Kim (2013) proposed Volumetric Shadow Analysis (VSA) based automatic building height extraction method by using mono-scopic imagery. The proposed algorithm offers several advantages, such as, less impact of shadow detection error on estimation of height of building, need not to consider all building boundaries and whole shadow region during estimation of height, etc. Further, performance of the proposed method has been tested on HRS image and compared to manually extracted building height. The experimental result shows that, RMSE in estimation of building height using proposed method has been less than 3m.

Raju et al. (2014) estimated height of the buildings using two different methods, sun-satellite geometry method as proposed by Shettigara and Sumerling (1998) and ratio method, which is a manual method, in which shadow width has been measured manually. Further, different parameters with respective to position of sun and satellite at the time of imaging, have been used in order to estimate height of building (Eq. 1). Initially, building and shadow extraction has been carried out by both manual and automatic method using ENVI's object-based classification. However, methodology for measuring shadow width, which has been a critical step in estimation of height of building, has not been clearly explained. Since, shadows casted by buildings having different size and shapes and do not have uniform shape which further adds difficulty in measuring shadow width. Further, results show that, mean error in estimation of height using ratio method/manual method (0.67m) have been better than rule based/automatic method (0.96m), yet rule based method have been best suited for estimation of height. Since, manual method is time consuming and requires more knowledge and selection of training sample, it slows down processing speed of the proposed methodology.

Wang et al. (2014) also used sun satellite geometry method, in order to estimate height of building using Chinese No.3 resource satellite (ZY3) image, for Shanghai, China. In the proposed methodology, initially, building and shadow region have been classified using MBI, MSI and eCognition based object-oriented approach. Further, height of building has been estimated using following equation:

$$H = S\,\frac{tan\omega\; tan\Theta}{tan\Theta - tan\omega} \quad (5)$$

where, S is the shadow width, ω and Θ are the altitude of the sun and satellite respectively. Further, obtained result shows that absolute and relative error during estimation of height of building have been below 3m and below 5% respectively.

The detailed literature survey suggests that accuracy in estimation of building height from satellite image is highly dependent on accuracy of shadow extraction and shadow width measurement procedures. Above studies largely avoided the consideration of various shapes of the building, their orientation, and shadow cast by these buildings due to their different/unlike shape.

3 METHODOLOGY

Methodology adopted for estimation of height of building using sun-satellite geometry method is shown in Fig. 3. The proposed methodology estimates height of the building using relationship between shadow cast by building and sun-satellite azimuth and sun elevation angle.

The input to the proposed methodology is a shadow image (Fig 4b), which has been obtained from the object-based building extraction technique (Gavankar & Ghosh, 2019), shown in Fig 4a. The input image (Fig 4b) includes shadow objects cast by various buildings in the region.

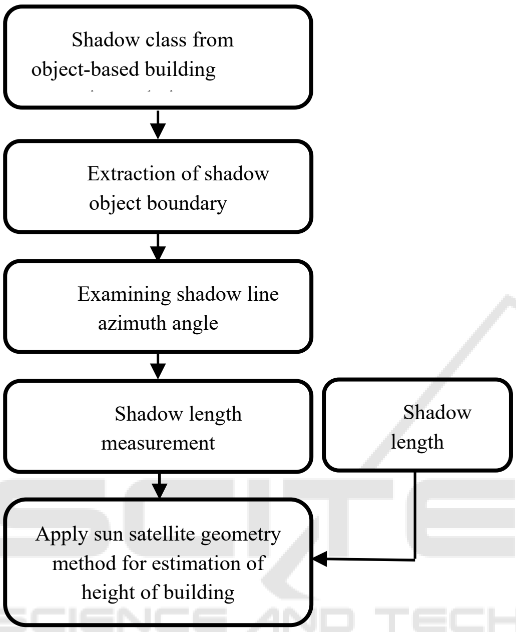


Figure 3: Methodology adopted for estimation of building height.

Sun and satellite geometry (angle) at the time of image acquisition reveals important information, which may be used to estimate height of building. The intrinsic relationship of angle produced by sun-satellite with respective to building normal, length, and width of the shadow cast by building together has been used to estimate height of building

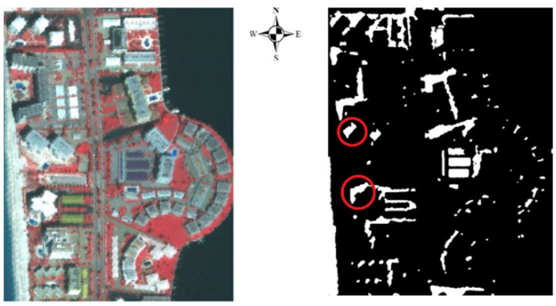


Figure 4: (a) Scene selected from IKONOS MS data set (b) Shadow class.

In general, there are three important steps while estimating height of building, based on the analysis of shadow.

i) Extraction of shadow from satellite image
ii) Measurement of shadow width
iii) Estimation of height of building using sun-satellite geometry

3.1 Extraction of Shadow from Satellite Image

In general, extraction of shadow from optical imagery has been a fundamental step in estimation of height of building using shadow. Various studies have been carried out in order extract shadow from satellite imagery (Sarabandi et al., 2004; Arévalo et al., 2008; Liu and Yamazaki, 2012; Song et al., 2014), which have been further found effective during estimation of height of building.

Considering various advantages of OBIA, here, an object-based technique has been used to extract shadow from HRS image. The proposed shadow extraction methodology consists of three steps;

i) **Improving spatial resolution of MS image:** In this step, HCS pan sharpening algorithm has been used to enhance spatial resolution of multispectral image
ii) **Segmentation:** Segmentation has been carried out by using ENVI's edge-based segmentation method.
iii) **Classification:** Unsupervised *K*-means clustering algorithm has been used to classify segmented image into five predefined classes, such as, vegetation, roads, barren land, building, and shadow. Further, the extracted shadow class has been used for estimation of height of building.

3.2 Measurement of Shadow Width

Measurement of shadow width has been a major issue during estimation of height of building. In general, shadow width may be calculated by measuring the distance from detected corner of that building to the respective corners of shadow. However, relating or finding corresponding corners of building and shadow is a challenging task. In order to overcome this problem the relation (Eq.6) used by (Shettigara and Sumerling, 1998; Raju et al., 2014) has been used.

$$S = \frac{Area\ of\ shadow\ zone}{Width\ of\ the\ zone} \quad (6)$$

where,

S is the width of shadow.

Further, the obtained shadow width along with sun-satellite elevation and azimuth angles at the time of image acquisition has been used to estimate height of building.

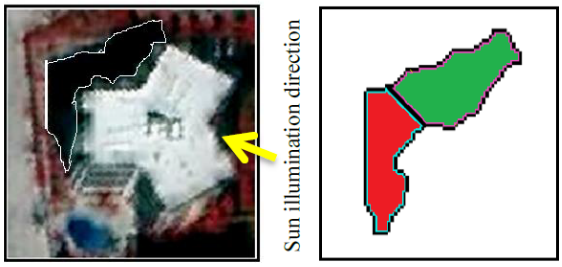
The proposed methodology considers, azimuth of shadow line and sun illumination direction while measuring width of shadow cast by building. However, in the proposed methodology (Shettigara and Sumerling, 1998; Raju et al., 2014) has not considered following issues related to the shadow cast by special or irregular shaped buildings:

i) Shadow cast by special or irregular shaped buildings are also irregular in nature.
ii) These shadows may be extended in one direction due to building line azimuth, shape of building, and sun azimuth at the time of image acquisition.
iii) A part of the building, which is opposite to sun illumination direction, also casts shadow of roof of building, instead of the shadow of vertical edges of the building.

In addition, during field/ground observation, it has been observed that, shadow cast by building edges which is exposed to direct sunlight gives true shadow with respect to vertical edges (height) of building and that shadow line observes uniform angle *theta* (θ) with respect to North. However, edges of building opposite to sun illumination direction cast shadow of roof of building instead of vertical building edges and do not follow any specific angle with respect to North. Similar observations may be seen for a typical shape building and extracted shadow, cast by such building, in the study area (Fig. 5).

Here, shadow cast by a typical shape building (Fig. 5), clearly shows the relationship between sun illumination direction and the shadow cast by building. Green portion represents shadow cast by vertical edges of the building, which have been directly exposed to the sun illumination direction and clearly observes a uniform angle *theta (θ)* with respect to North. However, the red portion represents shadow cast by part of building, which is opposite to sun illumination direction and does not follow any regular relationship with North direction and building line. In addition to that, shadow cast by roof of building may be seen in the red portion of the shadow zone. Unlike other shadow edges, a straight vertical line may be seen, which represents projection of roof edge of building.

In order to measure the actual width of the shadow cast by a building, parallel lines to shadow line connecting every two opposite edge pixels of shadow edges (E(x1,y1) to E(x2,y2)), considering sun illumination direction have been drawn. However, during measuring shadow length, shadow cast by part of building exposed to sun illumination direction has been considered (green portion in Fig 5 (b)). Since, a part of building, which has been exposed to sun illumination direction, projects shadow with respect to vertical edges (height) of building. Further, the line having maximum length amongst all parallel lines has been considered as width of shadow cast by building and used further for estimation of height of building (Fig. 6).



(a) Typical shape building (b) Extracted shadow

Figure 5: Shadow cast by a typical shape building.

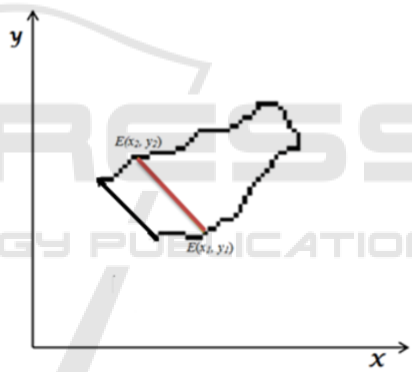


Figure 6: Measurement of shadow width.

3.3 Measurement of Shadow Width

Sun-satellite geometry at the time of image acquisition plays a key role during estimation of height of building. A part of the shadow seen on satellite image depends on its location with respect to Sun and building (Raju et al. 2014). A typical end view of sun-satellite-building geometry at the time of imaging is shown in Fig. 7 and 8 respectively.

In this method, while estimating height of object (building), following assumptions have been made.

i) Object (building) has been assumed to be vertical, i.e. object is perpendicular to surface of Earth which is also flat.
ii) Shadow has been projected directly onto flat ground.

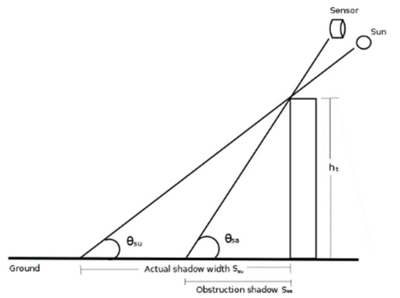


Figure 7: End view of the sun-satellite-building configuration as seen during imaging (Raju et al., 2014).

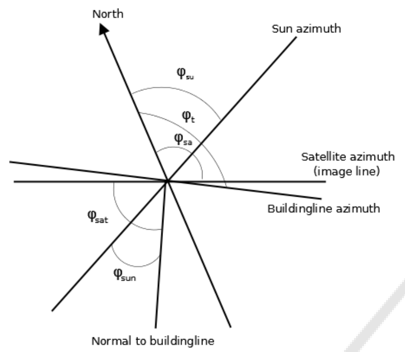


Figure 8: Sun-satellite-building geometry (Raju et al., 2014).

i) Shadow line starts immediately from the bottom of the building line.

Following equations have been derived by using the sun-satellite geometry (Fig. 7, Fig. 8), shadow cast by building, and assumptions made. The width of shadow along the sun azimuth *(S_{su})* may be expressed as

$$S_{su} = \frac{h_t}{tan(\theta_{su})} \quad (7)$$

The width of shadow obstructed along azimuth of sensor by the object in the sensor's field of view *(S_{sa})*

$$S_{sa} = \frac{h_t}{tan(\theta_{sa})} \quad (8)$$

And

$$\phi_{sun} = \phi_{sa} + 90 - \phi_t \quad (9)$$

$$\phi_{san} = \phi_{su} + 90 - \phi_t \quad (10)$$

where, ϕ_{su}, ϕ_{sa}, ϕ_t are the azimuth of sun, image scan line (satellite azimuth), and building line respectively. Further, height of building *(h_t)* may be represented as

$$h_t = {}^{S}\!/_{\{[cos(\phi_{sun})\, tan(\theta_{su})] - [cos(\phi_{san}) \tan(\theta_{sa})]\}} \quad (11)$$

where, S is the shadow width (area of the shadow zone divided by the length of the zone).

4 STUDY AREA

Extraction of building from remotely sensed data has been a difficult task due to their diverse structural and spectral

IKONOS data of Dec 21, 2006, has been taken for study, is located close to Naples, USA, lying between the latitude and longitudes ranges of (26°11´45´´N to 26°10´45´´ N) and (81°48´56´´W to 81°48´ 30´´ W) respectively (Fig. 9).

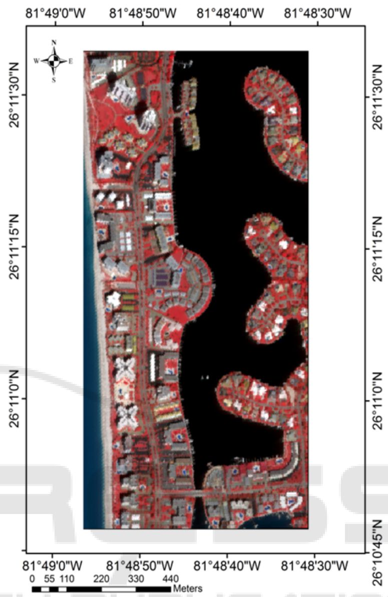


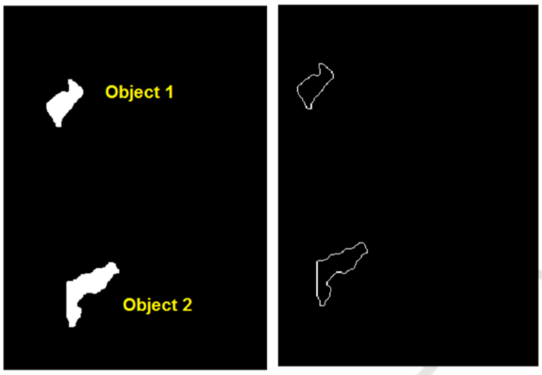
Figure 9: Study area/Location map: Naples, USA.

Naples is located near the Gulf of Mexico in southwest Florida, known for its high-end shopping and golf courses. Naples is one of the wealthiest cities in the United States, with the sixth highest per capita income in America. According to the United States Census Bureau, the city has a total area of 42.59Km2. The uniqueness of this image selected is that the buildings have different shapes interspersed with good coverage of vegetation, having different layout. Some of the buildings are condominium type having a good length of the shadow, while others low height isolated buildings, very typical of resort areas.

5 RESULT AND DISCUSSION

Estimation of building height from HRS data is one area to tropical interest to researchers. Here, shadow of building has been defined separately as a class, and obtained from object-based building extraction technique (Gavankar & Ghosh, 2019). The same has been used as an input to estimate height of the building. The input shadow class, obtained from object-based technique is shown in Fig. 4(b).

Further, building shadow objects highlighted in Fig 4(b) have been selected for estimation of height of building (Fig. 10(a)). The shadow objects selected includes, the shadow cast by a regular shape building (Object 1) and a typical or special shape building (Object 2). Thereafter, boundaries of selected objects have been extracted 10(b)), and used further for estimation of height of building.



(a) Shadow objects (b) Boundaries of shadow objects

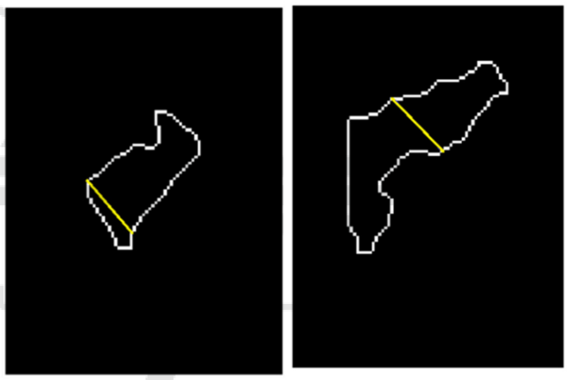
Figure 10: Selected building shadow objects; object 1: shadow cast by regular shape building, object 2: shadow cast by typical or special shape building.

In the next step, considering azimuth of sun illumination and shadow line azimuth, parallel lines connecting every two opposite edge pixels of shadow edges have been drawn. Thereafter, the line having maximum length amongst all the parallel lines has been selected as the width of shadow zone. Table 1 shows the length of sample/few parallel lines in terms of number of pixels for both shadow objects. Fig. 11 (a) and (b) shows selected maximum length shadow line for both shadow objects.

After selecting maximum length of the line, width of the shadow zone is calculated by considering number of pixels comprises line and resolution of image (i.e number of pixels comprises line_× image resolution) (Table 2).

Table 1: Length of parallel lines.

Shadow object 1				Shadow object 2		
X	Y	Length of the line		X	Y	Length of the line
43	364	22		63	537	21
44	363	21		64	536	21
45	362	21		66	536	20
47	361	20		67	536	18
48	360	20		69	536	17
49	359	20		71	535	17
50	358	20		73	534	17
51	357	20		74	533	18
52	356	20		75	532	20
55	355	18		76	531	22
56	354	18		78	530	23



(a) Shadow object 1 (b) Shadow object 2

Figure 11: Maximum length line for measuring shadow width.

Table 2: Width of shadow zone.

Shadow object	Length of the line (pixels)	Resolution of image (m)	Width of shadow zone (m)
Object 1	22	1	13.20
Object 2	23	1	13.80

(Shettigara and Sumerling 1998; Raju et al., 2014) used Bounding/Enclosing rectangle method to measure the width of shadow zone. In Bounding Rectangle method, a rectangle with minimum area of arbitrary orientation enclosing every pixel of the polygon under consideration has been drawn (Fig. 12). Further, width of rectangle which has been considered as width of shadow zone and area of rectangle has been used to estimate height of building. Table 3 shows area and width of rectangle obtained by using Bounding Rectangle method.

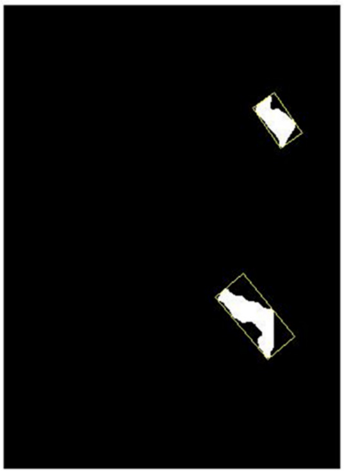


Figure 12: Minimum bounding rectangle for measuring shadow width.

Table 3: Area and width of minimum bounding rectangle.

Shadow object	Area of rectangle (sqm)	Width of rectangle (m)	Width of shadow zone (m)
Object 1	397.49	14.48	14.48
Object 2	897.52	19.91	19.91

Thereafter, height of building has been estimated using sun-satellite geometry method (Shettigara & Sumerling, 1998; Raju et al., 2014), as explained in *Section 3.3*. In sun-satellite geometry method, the required sun and satellite elevation and azimuth angle have been acquired from image metadata file (Table 4).

Table 4: Sun and satellite elevation and azimuth angle.

Sun elevation	49.3
Sun azimuth	163.7
Satellite elevation	63.8
Satellite azimuth	208.2

Thereafter, width of shadow (S) and height of the building (h_t) have been calculated using Eq. 6 and 11 respectively and obtained results are given in Table 5.

Table 5 shows that for regular shape building (building 1) error in estimation of height of building is less (2.55 m), however for typical or special shape building (building 2) error is high (22.65 m). The error observed in estimation of building height for typical or special shape building is mainly due to the 3 reasons as explained in *Section 3.2*. Hence, methodology proposed by Raju et al., (2014) for estimation of height of building gives acceptable result for regular shape building, however, may not be suitable for special or typical shape buildings.

Table 5: Estimation of height of building using Raju et al., (2014) method.

Building	Width of shadow (S) (m)	Estimated height of building (h_t) (m)	Actual height of building (Emporis Dictionary) (m)	Error in height estimation (m)
Building 1	27.45	31.55	29	2.55
Building 2	45.08	51.22	28.57	22.65

In order to resolve the problem in estimation of height of building having special or typical shape, sun-satellite-shadow relationship proposed by Comber et al., (2012) has been used (Eq. 4) and the results obtained are given in Table 6.

Table 6: Estimation of height of building using Comber et al., (2012) method.

Building	Width of shadow (W) (m)	Estimated height of building (H) (m)	Actual height of building (Emporis Dictionary) (m)	Error in height estimation (m)
Building 1	13.20	28.09	29	0.91
Building 2	13.80	29.36	28.57	0.79

Table 6 shows that error in estimation of height of building is acceptable for both regular and typical or special shape buildings. However, Comber et al., (2012) have not considered methodology to measure the width of the shadow cast by the building, which is an important criterion during estimation of height of building, especially for typical or special shape building.

In this study, methodology for measuring width of shadow cast by the building has been proposed. Further, proposed methodology addresses the fundamental issues related to the measurement of width of shadow cast by the typical or special shape building. Here, sun illumination direction has also been considered during shadow width measurement. Proposed methodology has been found suitable to measure the width of shadow cast by building, during estimation of height of building using Comber et al., (2012) method.

6 CONCLUSION AND FUTURE SCOPE

High spatial resolution satellite image and OBIA approach provides a comprehensive methodology to detect and extract shadows cast by buildings. Proposed object-based framework successfully extracts shadow precisely from HRS multi-spectral image, which is a preliminary requirement for estimation of height of building.

Methodology proposed for measuring width of the shadow zone considering sun illumination direction and orientation of building has been found efficient during estimation of height for all types of different shape buildings. The error observed in estimation of height of building for both regular shape and special shape buildings are 0.91 m. and 0.71 m. respectively, which is acceptable when compared to earlier studies. Proposed shadow measuring technique for estimation of height of building may be tested for other typical or special shape buildings.

7 MAJOR ACHIVEMENT

Methodology for measuring width of the shadow zone has been proposed to estimate height of all types of buildings considering effect of sun illumination direction and orientation of building. Proposed methodology resolves an important issue of measuring width of the shadow zone, especially for shadow cast by special or typical shape building, which is novel in the sense that no such study has been reported earlier.

REFERENCES

Arévalo, V., González, J. and Ambrosio, G., 2008. Shadow detection in colour high-resolution satellite images. International Journal of Remote Sensing, 29(7), 1945–1963.

Brunner, D., Lemoine, G., Bruzzone, L. and Greidanus, H., 2010. Building height retrieval from VHR SAR imagery based on an iterative simulation and matching technique. IEEE Transactions on Geoscience and Remote Sensing, 48(3), 1487–1504.

Chen, D., Shang, S. and Wu, C., 2014. Shadow-based building detection and Segmentation in High-resolution Remote Sensing Image. journal of multimedia, 9(1), 181–188.

Cheng, F. and Thiel, K.H., 1995. Delimiting the building heights in a city from the shadow in a panchromatic SPOT-image—Part 1 test of forty-two buildings. Remote Sensing, 16(3), 409–415.

Comber, A., Umezaki, M., Zhou, R., Ding, Y., Li, Y., Fu, H., Jiang, H. and Tewkesbury, A., 2012. Using shadows in high-resolution imagery to determine building height. Remote sensing letters, 3(7), 551–556.

Dare, P.M., 2005. Shadow analysis in high-resolution satellite imagery of urban areas. Photogrammetric Engineering & Remote Sensing, 71(2), 169–177.

Gavankar, N.L. and Ghosh, S.K., 2018. Automatic building footprint extraction from high-resolution satellite image using mathematical morphology. European Journal of Remote Sensing, 51(1), pp.182-193

Gavankar, N.L. and Ghosh, S.K., 2019. Object based building footprint detection from high resolution multispectral satellite image using K-means clustering algorithm and shape parameters. Geocarto international, 34(6), pp.626-643

Guida, R., Iodice, A. and Riccio, D., 2010. Height retrieval of isolated buildings from single high-resolution SAR images. IEEE Transactions on Geoscience and Remote Sensing, 48(7), 2967–2979.

Guillaso, S., Ferro-Famil, L., Reigber, A. and Pottier, E., 2005. Building characterization using L-band polarimetric interferometric SAR data. IEEE Geoscience and Remote Sensing Letters, 2(3), 347–351.

Guo, J., Liang, L. and Gong, P., 2010. Removing shadows from Google Earth images. International Journal of Remote Sensing, 31(6), 1379–1389.

Hartl, P. and Cheng, F., 1995. Delimiting the building heights in a city from the shadow on a panchromatic SPOT-image: Part 2: Test of a complete city. Remote Sensing, 16(15), 2829–2842.

Lee, T. and Kim, T., 2013. Automatic building height extraction by volumetric shadow analysis of monoscopic imagery. International journal of remote sensing, 34(16), 5834–5850.

Liasis, G. and Stavrou, S., 2016. Satellite images analysis for shadow detection and building height estimation. ISPRS Journal of Photogrammetry and Remote Sensing, (119), 437–450.

Liu, W. and Yamazaki, F., 2012. Object-based shadow extraction and correction of high-resolution optical satellite images. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 5(4), 1296–1302.

Massalabi, A., He, D.C., Benie, G.B. and Beaudry, E., 2004. Detecting information under and from shadow in panchromatic IKONOS images of the city of Sherbrooke. In Proceedings of IEEE on Geoscience and Remote Sensing Symposium (IGARSS04), (3), 2000–2003.

Raju, P.L.N., Chaudhary, H. and Jha, A.K., 2014. Shadow analysis technique for extraction of building height using high resolution satellite single image and accuracy assessment. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40(8), 1185.

Sarabandi, P., Yamazaki, F., Matsuoka, M. and Kiremidjian, A., 2004. Shadow detection and radiometric restoration in satellite high resolution images. In Proceedings of IEEE 4th Symposium on Geoscience and Remote Sensing (IGARSS), (6), 3744–3747.

Shao, Y., Taff, G.N. and Walsh, S.J., 2011. Shadow detection and building-height estimation using IKONOS data. International journal of remote sensing, 32(22), 6929–6944.

Shettigara, V.K. and Sumerling, G.M., 1998. Height determination of extended objects using shadows in SPOT images. Photogrammetric Engineering and Remote Sensing, 64(1), 35–43.

Sırmaçek, B. and Ünsalan, C., 2008. Building detection from aerial images using invariant color features and shadow information. In 23rd IEEE International Symposium on Computer and Information Sciences (ISCIS), 1–5.

Sırmaçek, B. and Ünsalan, C., 2011. A probabilistic framework to detect buildings in aerial and satellite images. IEEE Transactions on Geoscience and Remote Sensing, 49(1), 211–221.

Song, H., Huang, B. and Zhang, K., 2014. Shadow detection and reconstruction in high-resolution satellite images via morphological filtering and example-based learning. IEEE Transactions on Geoscience and Remote Sensing, 52(5), 2545–2554.

Sportouche, H., Tupin, F. and Denise, L., 2011. Extraction and three-dimensional reconstruction of isolated buildings in urban scenes from high-resolution optical and SAR spaceborne images. IEEE Transactions on Geoscience and Remote Sensing, 49(10), 3932–3946.

Wang, J. and Wang, X., 2009, May. Information extraction of building height and density based on quick bird image in Kunming, China. In IEEE Joint Event on Urban Remote Sensing, 1–8.

Wang, X., Yu, X. and Ling, F., 2014. Building heights estimation using ZY3 data-A case study of Shanghai, China. In IEEE international Symposium on Geoscience and Remote Sensing (IGARSS), 749–1752.