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Automatic 3D City Model Extraction from Cartoset-I Stero Pair for Application Domain

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Abstract

3D city models using stereo images are being used predominantly in urban designing. To extract 3D models, a tool named 3D Modeller has been developed using various open source tools.The tool generates 3D city models from Cartosat-1 satellite stereo images using NASA's Ames Stereo Pipeline and other open source tools. 3D Modeller also estimates the solar potential and rooftop rainwater harvesting of buildings for smart city use cases and uses GRASS GIS 7 and python 2.7 for the estimation. Dehradun is one of the fastest growing city of India and is one of the proposed smart city by the Government of India. The structure of the city is contiunously expanding, thus creating the need of 3D visualization of the city for sustainable planning. 3D model is generated for small area of Dehradun and is validated through field survey. Additionally, solar potential &rooftop rainwater harvesting for the buildingsare also estimated and validated.

Keywords: Bundle Adjustment,Digital Surface Model, Image Matching, Rainwater Harvesting, Solar Potential

Introduction

The way of representing the earth surface have changed drastically over past years. 2D maps have been replaced by 3D models. New techniques and methods have evolved in the automation of 3D model generation. 3D city modelling is becoming more and more important for use in applications like urban planning, solar potential assessment, land monitoring, gaming, etc. To fulfill the requirements, Digital Surface Modelsare generated. A Digital Surface Modelrepresents the elevation of topography and all natural and man-made features located on the earth's surface. Digtial Surface Models can be generated from various sources like High-resolutionstereo-pairs from satellite, active remote sensing like Lidar, spot height measurement. The Digital Surface Models are then used to generate 3D models. In general, 3D model extraction can be manual, semi-automatic and fully automatic. As we move from manual to automatic, time consumption as well as accuracy decreases.

3D modelling from satellite stereo pairs is becoming more and more popular as it is real time, cheap and efficient technique. 3D GIS simulation always communicates more effectively than 2D.Our group has recently developed a linux based user interfaces which specifically work with Cartosat-1 satellite stereo images. The tool is developed using different open sources tools namely Ames Stereo Pipeline for DSM generation and GRASS GIS for solar potential estimation. We combined these tools and developed a new user interface which automatically does all the processing without any human intervention.This objective of this study is to extract 3D models of LOD 1 from Cartosat-1 stereo pairswith least human participation using 3D Modeller. Moreover, Solar potential estimation and rooftop rainwater harvesting estimation, which can be implemented as a use case for Smart City.

1.1 Motivation

The concept of smart cities is becoming popular nowadays as these cities use different types of technology to fulfill its basic requirements like electricity and water. Electricity generation is an important aspect of smart cities. With the rapid urbanization of cities, the electricity requirement, as well as water requirement, is increasing continuously. Solar energy can be used to fulfill the energy requirement and rooftop rainwater harvesting can be done to cater water requirement of the cities. These technologies require 3D modelling of the cities for identification of the suitable sites. Current methods of 3D modelling from satellite imagery gives less accurate building footprints and building heights.

1.2 Related Studies

Studies have been done to find the different methods and tools available to generate 3D models from satellite stereo pairs.

One such study by (Krauß et al. 2005) shows a Column Algorithm approach for extracting DSM from stereo images. This approach is based on epipolar geometry which uses the line for line correspondences to find a correlation between stereo images. Since, there will be differences in the brightness and contrast between both images, radiometric correction of the images needs to be done before running the column algorithm. Based on this correlation DSM is generated.(El Garouani and Alobeid 2013) shows the use of LPS (Leica Photogrammetry Suite), a widely used ERDAS tool for the generation of DSM for generating DSM from aerial image stereo pairs using image matching method.

To generate DSM, Ground Control Points or tie points are collected to correlate the stereo images. Then, Digital Image Matching is done using LPS, which gives the output of image location of ground points which then used to extract DSM.

There is an open source software named Ames Stereo Pipeline (ASP), which was developed by the Intelligent Robotics Group (IRG), in the Intelligent Systems Division at the National Aeronautics and Space Administration (NASA) Ames Research Center in Moffett Field, CA. This software is capable of automatic generation of high-quality DEM's with minimal human interventions.This software runs on Linux platform and is command based.First step involved in the generation of DEM is bundle adjustment, which removes the errors in camera position and orientation. The goal of bundle-adjustment is to findthe position of 3D point and camera parameters that minimize theerror in re-projection. (Agarwal et al. 2010). If external DEM is provided, then, map projection can be used to reproject the stereo images over external DEM. After correcting the camera positions and reprojecting the images, stereo command is used to generate point file from stereo image. This command includes five main steps namely pre-processing for alignment of left and right images, disparity map initialization or correlation for computation of correspondences between pixels in the left and pixels in the right image, subpixel refinement for adjustment of all valid pixels from correlation step, triangulation for determination of point in 3D space. The point file generated is then passed to point2dem command to create DSM in Geo-TIFF format.(NASA 2015).

(Sharma et al. 2015) uses building footprint to get the elevation information from the Digital Surface Model. They first conditionedthe Digital Surface Model for the removal of spikes and depressions. A buffer of 25 m along the building footprint is then applied for extraction of the minimum elevation value. This minimum elevation represents the ground elevation with respect to the building footprint. Average elevation value within the building footprint represents the elevation of the building footprint. To extract the actual height of the building, the ground elevation is subtracted from the average elevation value.

The overview of solar potential is taken from (Biljecki et al. 2015) who usedSolar3Dcity, an open source script that for the calculation of annual solar irradiation of a building in kWh/m2/year. They describe that the estimation of solar irradiation is one of the most prominent use cases for 3D city models. Solar irradiance is the instantaneous rate ofenergy that is being delivered to a surface (power per unit area), usually expressed in W/m2. If solar irradiance is integrated over time, it is then called insolation and is usually expressed in kWh/m2/year. For installation of a photovoltaic panel on rooftop surface of buildings, normalized solar irradiation is multiplied with an area of the surface to get solar irradiation in kWh/year. Solar irradiation differs at different locations on earth due to the difference in day lengths and position of the sun, differs between same rooftop area of buildings due to orientation and inclination of the roofs.

GRASS GIS 7 is an excellent open source Linux tool for calculating solar irradiation of area using vector as well as raster data. It offers more than 350 modules for data processing, management, analysis and visualization. It offers shell scripting and supports more than 40 raster formats. (Weyrer 2011). The module r.sun computes the direct(beam), diffuse,reflected, and global solar irradiation raster maps for given day.(Jaroslav et al. 2007) To calculate solar irradiation for multiple days, a module named r.sun.daily can be used which takes elevation raster map, aspect (azimuth angle of the solar panel), slope (inclination angle of the solar panel), start day and end day as an input parameter to compute solar irradiation.(Vaclav and Anna).

(Joshi and Khandagale 2011)defines that the total amount of water that is received in the form of rainfall over an area (a) is called the rainwater endowment of that area. Out of this, the amount that can be effectively harvested is known as the water harvesting potential which is the product of rainfall(r) in mm to collection efficiency(μ). There is another constant(k) with value 0.80 which incorporates the evaporation and other variables. The multiplication of this constant with water harvesting potential will give the actual value of rainwater harvesting potential.

Rainfall pattern and total rainfall determine the feasibility of a rainwater harvesting system. In areas where rainfall occurs regularly throughout the years, the storage requirement is low corresponding to low system cost and where total rainfall occurs during 1-2 months, a year requires a large storage of collected water for use in remaining days. The maximum intensity of rainfall decides the peak flow depending upon which the gutter size and diameter of the pipe is determined. Rainwater harvesting directly depends on the surface area of the roof. More the surface area more is the feasibility of rainwater harvesting system.(Committee 2008).

1.3 Study area

The study area chosen for the work is Dehradun, capital of Uttrakhand and one of the proposed smart city in Uttrakhand. (SmartCities 2015). Itis situated in the eastern part of Doon Valley, at the foothills of the Himalayas.The valley of Dehradun has acted as the center town between the Northern Himalayan region and Ganga plains in the south.(Tiwari et al.)

It has aspatialextent of 300 km2 with thelatitude of 300 20’ 19.81” N to 300 20’ 46.60” N and longitude of 780 02’ 20.54”E to 780 03’ 04.70” E.Dehradun is located near the main active thrust zone (Main Boundary Thrust and Main Central Thrust) in the Himalayas.

The city is situated within one of the highest seismic hazard zones of the country (Tiwari et al.).

Figure 1 Study Area

1.4 Datasets

For the study,fore and aft scenes of Cartosat-1 having spatial resolution of 2.5 m is used to generate the Digital Surface Model. The scenes are provided with Rational Functions Coefficients (RPC) in text files. These RPC are converted to xml file and used as input for DSM generation. Building footprints,extracted from IKONOS panchromatic image of resolution 1 m and multi-spectral band of 4 m using eCognition are taken to generate 3D models.Additionally, the existing low resolution DEM of 30m is taken from bhuvan to reproject the stereo images. Building heights from ground surveys through Total Station Survey will be used for accuracy assessment of height extracted from DSM.

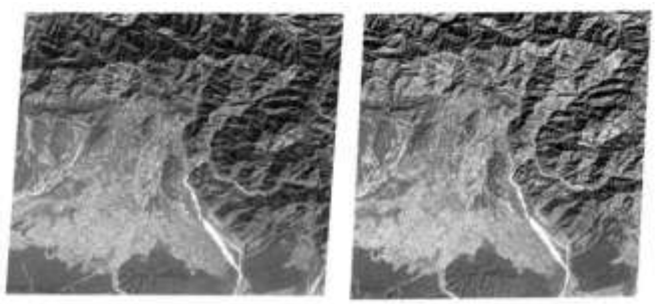

Figure 2: Cartosat-1 Fore and Aft images

1.5 Methodology

This study involves four main working processes. Three dimensional model extraction, solar potential estimation,rooftop rainwater harvesting estimation and comparison & validation of extracted data with collected data from field survey.

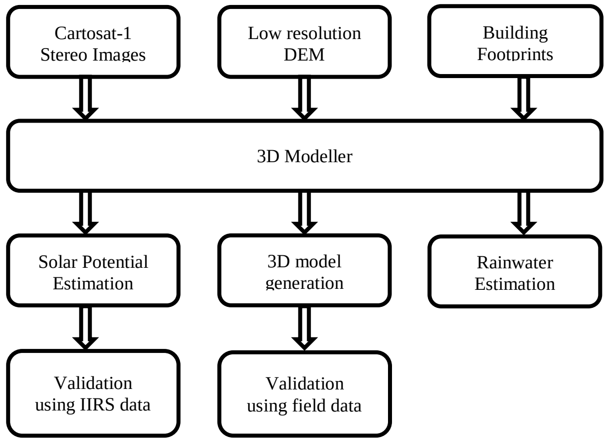

Figure 3: Methodology adopted for study

Three dimensional model extraction dealt with generation of 3D model using cartosat-1 stereo images, low resolution DEM and building footprints in '.shp' format as inputs to the tool and generating 3D model. To ectract building height, three cases are taken in which buffer of 25m (case 1), 15m (case 2) and 5m (case 3) is applied along the building footprints. Solar potential and rooftop rainwater estimation dealt with computing the solar irradiance in $Wh.m^{-2}$ using DSM generated during 3D modelling process as input.Rooftop rainwater harvesting estimation dealt with computing rainwater in liters using area of building footprints. Then, all the output is compared and validated using field data.

1.6 Workflow of 3D Modeller

3D Modeller uses multiple open source linux platform tools to generate 3D models. It takes Cartosat-1 stereo image, rpc's in text format, low resolution existing DEM and building footprints as input and generates 3D model in gml and kml format. For the generation of Digital Surface Model, the tool depends on NASA's Ames Stereo Pipeline software which requires image's rpc's to be in xml format. The tool primarily converts the rpc's of the stereo image into xml format using python.

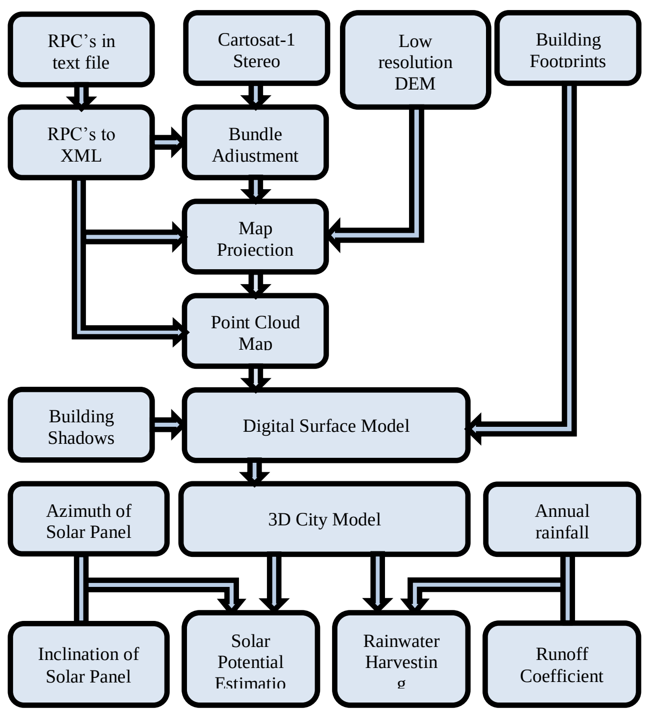

Figure 4: Work flow of 3D Modeller

Then, it bundle adjust the stereo images to remove camera's positional and orientation errors. After that images are projected over existing low resolution input DEM. Then, it generates point file through image matching technique. This point file act as input for the generation of Digital Surface Model.

For building height extraction and 3D model generation, the tool overlaps the building footprints vector data over the generated Digital Surface Model and creates a buffer along the building footprints. Then, it searches for the minimum elevation value within this buffer which represents the ground elevation with respect to the building footprint. After that, it searches for the maximum elevation value within the building footprint. Finally, it subtracts the minimum elevation value from maximum elevation value and stores the height information. The tool also provides an option to incorporate shadows of buildings. It takes shadow lengths of buildings as input in the attributes and computes the correction factor by average and root mean square. This correction factor is then multiplied by rest of the values to improve the accuracy of buildnig height.The output of the generated 3D model is in gml and kml format. This tool also stores height information in building footprints attributes.

Solar potential of an area depends largely onto the local weather data (historical weather cloud data), average amount of sunlight (solar radiation) per day at your location, tilt angle (tilt angle is based on setting the horizontal angle of the solar panels' plane so that it has maximum perpendicularity to the rays of the sun. This is dependent on latitude and time of year), azimuth angle, and most importantly location of the building. GRASS GIS 7 is an open source project and has been used for the calculations of the solar irradiation. It has module named r.sun which computes the solar irradiance in $Wh.m^{-2}.day^{-1}$. For calculation of solar irradiation for first fifteen days of May 2016, r.sun.daily is used which runs r.sun for multiple days. It takes elevation raster map, slope, aspect, start day and end day as input parameters and calculates global solar irradiance in $Wh.m^{-2}$ for given time interval.

Rooftop rainwater harvesting depends upon three major components: runoff coefficient, annual rainfall and surface area. The tool uses gdal module inpython script to calculate annual rainfall by extracts the area of the building footprints. This extracted area is multipliedby runoff coefficient and annual rainfall in mm to give amount of water that can be harvested in liters.

2. Results and Discussion

The output of the study includes Digital Surface Model, 3D city model of Dehradun city in both kml and gml format, generated solar map in tiff, solar potential estimation map, rooftop rainwater harvesting estimation map and at last comparision and validation of the output.

For building height extraction, three cases are taken in which buffer along footprints are marked at distance of 25 m, 15 m and 5 m. The height extracted from these buffer are shown in Figure 5,6, and 7.There is variation in building heights extracted in all three cases. Height of buildings decreases as we move from 25 m to 5 m buffer. These variations are mostly in buildings surrounded by trees or buildings near valleys due to variation of ground elevation within different buffer zones.

Figure 6: Buildings Hierarchy (25 m buffer)

Figure 5: Buildings Hierarchy (15 m buffer)

Figure 7: Buildings Hierarchy (5 m buffer)

For building 1, there is over estimation in case 1 and under estimation in case 3. For building 2, there is over estimation of height in all three cases. The reason of this overestimation is valley behind the building 1 and building 2. Building 6, 8, and 18 has under estimation in all three cases as it is located in congested area. The tool is unable to find the actual ground elevation value.

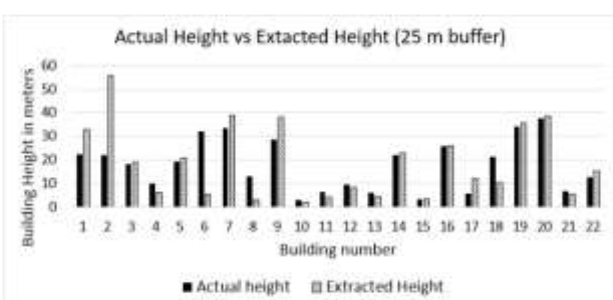

Figure 8: Comparision of Actual Height and Extracted Height (25 m buffer)

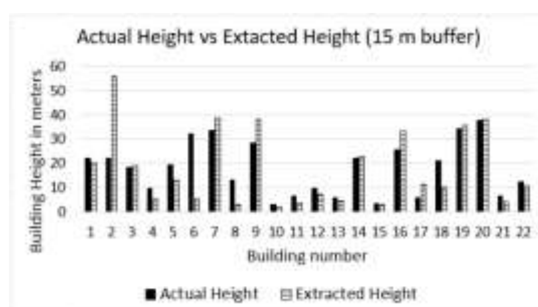

Figure 9: Comparision of Actual Height and Extracted Height (15 m buffer)

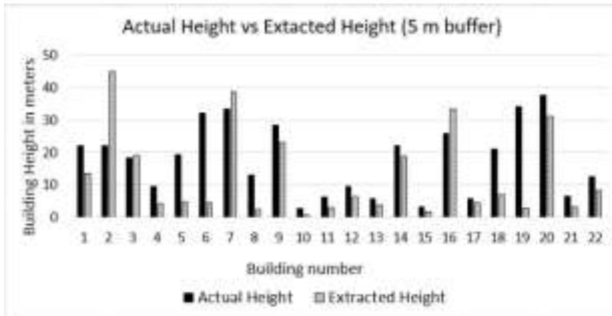

Figure 10: Comparision of Actual Height and Extracted Height (5 m buffer)

The average of error in building height in case 1, case 2, and case 3 are 5.97 m, 6.21 m, and 8.37 m respectively. After excluding the buildings with error due to topography, that is building 1,2,6,8 and 18, the average error in case 1, 2, and 3 is 2.32, 3.14, and 5.92 respectively.

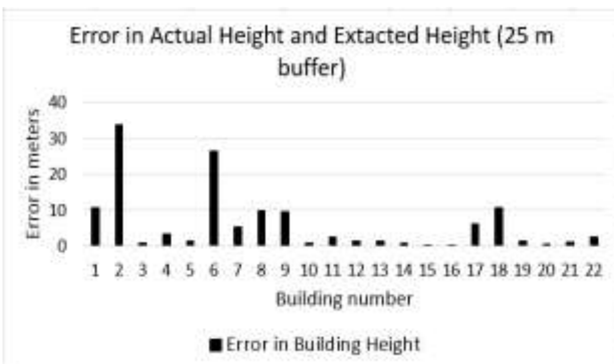

Figure 11: Error in Actual Height and Extracted Height (25 m buffer)

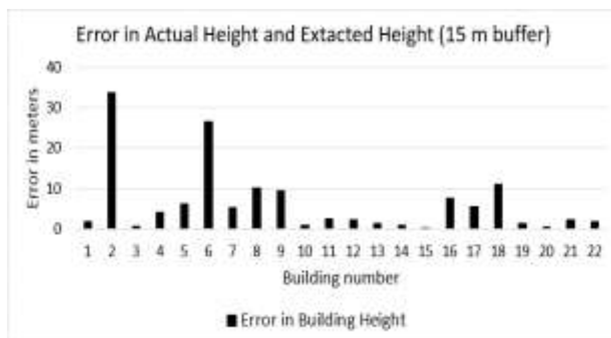

Figure 12: Error in Actual Height and Extracted Height (15 m buffer)

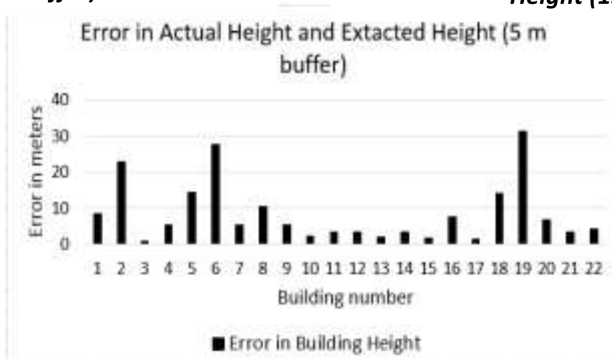

Figure 13: Error in Actual Height and Extracted Height (5 m buffer)

Comparision of error in all three cases as shown in figure 14 shows that error case 1 and case 2 are almost equal expect for building 1 where case 2 and building 5 and 16 where case 1 has less error. Case 3 is giving the most error and case 1 is giving the least error. For Dehradun city, case 1 is found to be optimal with least error.

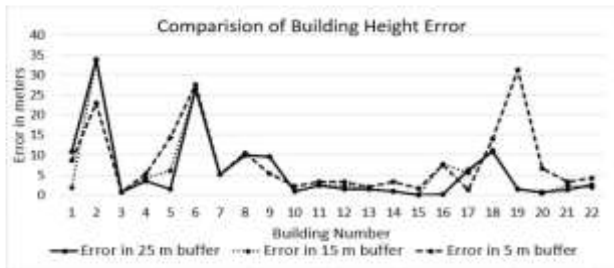

Figure 14: Comparision between Building Height Error

The solar potential of a building depends upon the area of roof as more the rooftop area more the sun radiation will fall on it. Hence, more solar radiations. The validation of solar irradiance estimation with building 22 shows that there is an overestimation of approximate 2,000 Wh/m^2 in the computed valueof 15 days. The reason for this overestimation can be the temperature variation from day to day and tool computes the solar irradiance with constant temperature.

As per URDPFI guidelines, the recommended consumption of electricity is 2.74 kWh per capita per day. For whole Dehradun city that is for 578,420 population, the electricity requirement is 1,584,870.8 kWh per day and the total incoming rooftop solar energy for Dehradun city buildings is 289,302.8 kWh per day. If proper solar energy harvesting systems are installed in Dehradun, 18.25 % of the total electricity requirement can be cater.

Figure 15: Rooftop Solar Potential Estimation in Wh

The rooftop rainwater harvesting directly depends upon the surface area of building roof. It can be predicted visually from the figure 15 that the buildings with more area has more rooftop rainwater harvesting estimation.

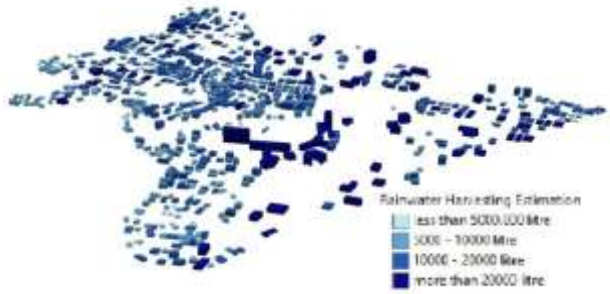

Figure 16: Rooftop rainwater Harvesting Estimation in liters

The main objective of the study was to accuratly extract the 3D model for the part of Dehradun using 3D modeller so that it can be used to estimate rooftop solar potential and rainwater harvesting estimation. The main advantage of this tool is that it works with least human participationreducing the chances of human errors. Applying this study over the whole Dehradun city, the increasing electricty and water demand can be cater by installing solar panels and rainwater harvesting systems on rooftops of buildings.

The study successfully extracted the accurate 3D model of part of Dehradun using 3D Modeller. From 3D Modeller, one can extract 3D city model for any city.This tool generates accurate Digital Surface Model from Cartosat-1 stereo pairs using NASA's Ames Stereo Pipeline. Then, it creates buffer along the footprints to extract ground value. The building height is computed by subtracting the ground value from the maximum elevation value within footprints. After extracting height, it generates 3D model in kml and gml formats using gdal module. It stores height value in attributes of footprint shapefile. Then, rooftop solar potential and rainwater harvesting estimation is computed using GRASS GIS and python respectively and are stored in shapefile attributes.

Three buffer of distance 5m, 15m, and 25m are marked and taken as three cases for building height extraction. Validation of building height in these three cases with ground data showed that error in height is least in case of 25m and is optimum in case of Dehradun.On validating the computed solar potential using GRASS GIS with ground data, the result showed the over-estimation in solar potential due to temperature difference.

Recommendations

The error in building heights can be reduced by using Digital Terrain Model. One can use Digital Terrain Model to extract ground elevation point and can extract building height.

The main advantage of using Digital Terrain Model is that it does not incorporate trees, buildings, and other man made objects. So, the accuracy in the ground elevation value increases. For accuratly estimation of rooftop solar potential, real time data from online sources can be used.

References

- Agarwal, S., Snavely, N., Seitz, S. M., & Szeliski, R. (2010). Bundle adjustment in the large. In Computer Vision–ECCV 2010 (pp. 29-42): Springer.
- Biljecki, F., Heuvelink, G. B., Ledoux, H., & Stoter, J. (2015). Propagation of positional error in 3D GIS: estimation of the solar irradiation of building roofs. International Journal of Geographical Information Science, 29(12), 2269-2294.
- Committee, G. W. A. R. I. S. (2008). Indian standards: Rooftop rainwater harvesting. In B. O. I. Standards (Ed.). New Delhi.
- El Garouani, A., & Alobeid, A. Digital Surface Model generation for 3D City Modeling (Fez, Morocco). In Eighth National GIS Symposium in Saudi Arabia,"The Road For Building Saudi Arabia GIS" organized by the high Committee of the GIS at the Eastern Province, 2013
- Joshi, V., & Khandagale, S. (2011). Rainwater Harvesting: Grab hold of Water Where it Falls!
- Krauß, T., Reinartz, P., Lehner, M., Schroeder, M., & Stilla, U. (2005). DEM generation from very high resolution stereo data in urban areas. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences VOLUME XXXVI.
- NASA, A. R. C. (2015). The Ames Stereo Pipeline, NASA's open source automated stereogrammetry software. In I. R. Group (Ed.), (2.5.1 ed., Vol. 41, pp. 2364).
- Sharma, S. A., Agrawal, R., & Jayaprasad, P. (2015). Development of '3D City Models' using IRS Satellite Data. Journal of the Indian Society of Remote Sensing, 1-10.
- SmartCities (2015). http://www.smartcitiesprojects.com/will-dehradun-be-included-in-smart-cities-mission/. Accessed July 2015.
- Tiwari, P. S., Pande, H., & Nanda, B. N. Building footprint extraction from IKONOS imagery based on multi-scale object oriented fuzzy classification for urban disaster management.
- Vaclav, P., & Anna, P. https://grass.osgeo.org/grass70/manuals/addons/r.sun.daily.html. Accessed May 3 2016.
- Weyrer, T. N. (2011). GIS Based Analysis of the Potential of Solar Energy of Roof Surfaces in Baton Rouge, Louisiana. Department of Geography and Anthropology, Louisiana State University, Baton Rouge, Louisiana, USA.