

### **BIO-DATA**

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# **LiDAR and High Resolution stereo satellite images for 3D mapping**

## **1.0. Introduction**

Most of the work pertaining to 3D mapping, in the developing countries, is still carried out using Aerial photographs or conventional ground surveys. The emergence of new technologies like LiDAR data and High resolution satellite stereo imagery has shown promising potential to replace some of the existing process in traditional Photogrammetry using aerial imagery. The use of LiDAR and high resolution satellite stereo imagery has gained a major importance in creation of DEM and Base Maps in the western parts of the World. One of the major concerns of users in the developing countries is the creation of Digital Elevation Models (DEM) and Base Maps quickly. The paper presents some insights of how the researcher, corporate and other organizations can effectively use a combination of LiDAR data and high resolution satellite stereo imagery in a Photogrammetry environment for better productivity and reduction in cost.

## **1.1. Present 3D mapping practices**

Terrain data collection, which includes Digital Elevation Model (DEM) and Digital Terrain Model (DTM), is a 3D representation of a topographic surface, which will be derived from different methods. The Digital Elevation Model will satisfy two important requirements viz. imagery ortho-rectification and surface modeling applications. The accuracy of the Terrain Data refers to the degree of conformity of measurements with the actual elevations as measured in the field. Feature collection is a major process in Base and topographic map creation.

Following are some of the Traditional Methods of Terrain Data Collection (DEM & DTM Generation) and feature Collection.

- Conventional ground surveys (transits and theodolites)
- Electronic Distance Measurement (EDM) Devices
- Global Positioning Systems
- Classical Photogrammetric Techniques

Problems with these methods

- Labor Intensive
- Time-consuming
- Costly
- Dictated by conditions (time of year, sun angle, weather, etc.)
- May require data collectors to locate in-field

## 2.0 LiDAR Concepts

LIDAR (Light Detection and Ranging) is a very powerful and versatile remote sensing tool. LiDAR systems operate on similar principles as radar or sonar, but use a laser beam to scan the atmosphere. The laser scanner is mounted at the bottom of an airplane (similar to an aerial camera) along with an Inertial Measuring Unit (IMU) and Airborne GPS. Once airborne, the sensor emits rapid pulses of infrared laser light, which are used to determine ranges to points on the terrain below. Similar like photogrammetric GPS survey, the LIDAR system also requires a surveyed ground-base location to be established in the project area (Fig.1). LIDAR scanning can occur day or night, as long as clear flying conditions are present. Although features such as buildings and automobiles are included during scanning, these can be filtered through the various post-processing filtering techniques. Hence, the ground can be modeled as a “Bare Earth” Digital Terrain Model (DTM). LIDAR technology offers fast, real-time collection of 3-D points that are quickly employed to generate DTMs.

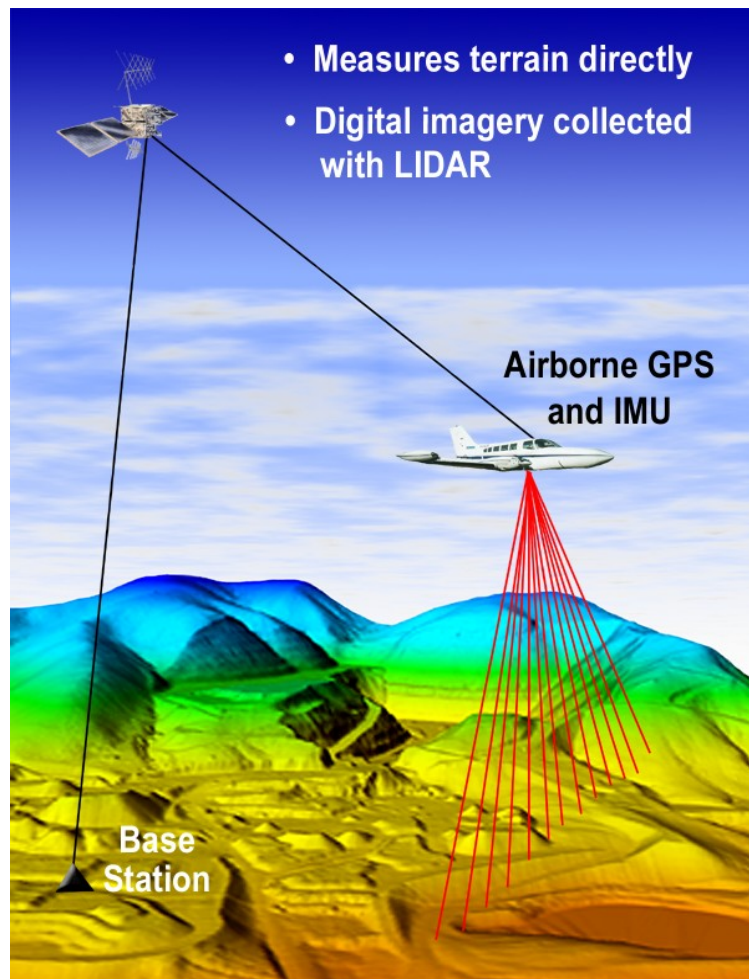


Fig.1. LiDAR point acquisition

Light Detection and Ranging (LiDAR) is a powerful aerial survey technology which is becoming popular in deriving Digital Elevation Models (DEM) and Digital Terrain Model (DTM) with a stunning accuracy of 10-15 Cm.

Most LIDAR systems use a scanning mirror to generate a swath of light pulses. Swath width depends on the mirror's angle of oscillation, and ground-point density depends on factors such as aircraft speed and mirror oscillation rate. Ranges are determined by computing the amount of time it takes light to leave an airplane, travel to the ground and return to the sensor. A sensing unit's precise position and attitude, instantaneous mirror angle and the collected ranges are used to calculate 3-D positions of terrain points as many as 100,000 positions or "mass points" can be captured every second. This ability of LIDAR systems to capture accurate spot heights at an extremely rapid rate is the principle reason behind LIDAR's success.

GPS data from the aircraft and multiple ground stations are processed together using sophisticated kinematic GPS post-processing software. The use of two or more ground stations provides quality control and improves the accuracy of the kinematic trajectory. As a result, the position (x, y, z) of an airborne GPS antenna at an interval of 0.5 or one second is calculated. The table below (Table.1) shows the LiDAR point density statistics

Post Spacing	Flying Height	FOV Degrees	Swath Width	Pulse Area HZ	Project Area Per Sq. Mi.	Point Per Sq. Mi.	Total No. Points
5m	10,000'	55	10,411'	23,100	16,841	384,763	6,479,800,000
3.5m	8,500'	45	6,602'	28,900	16,841	748,174	12,600,000,000
2m	6,000'	45	4,970'	32,800	16,841	1,324,420	22,299,500,000

Table.1. LiDAR data acquisition statistics

## 2.1 LiDAR processing & Results

### 2.1.1 LiDAR Processing

Laser scanner data has to be processed (correction of systematic errors, DEM extraction – filtering, feature detection and extraction) and packaged in a form for various applications. Because of the large volume of data generated (usually several GIGA bytes), the processing and packaging of the data has to be highly automated. The automation of the processing and packaging of laser scanner data is mostly focused on the "modeling of systematic errors", "filtering", "feature detection" and "thinning".

LiDAR data processing and analysis is a function of factors such as Terrain Roughness, Types of Earth Surface Features, Vegetation Density, Mixed Terrain and Surface Features, Spatial Resolution of the LiDAR data. Of the above tasks manual classification (including filtering) and quality control pose the greatest challenges, consuming an estimated 60 to 80% of processing time. Automated filtering algorithms have been developed but they share the common weakness that they are not universal.

### **2.1.2 Results**

By doing the filtering the unwanted LiDAR points (points that are not on the ground) can be removed. COTS and proprietary software's are available to do this exercise. Once the non ground points are removed, you will be getting ground points that can be used for bare earth modeling helping in creating ground contours. As LiDAR gives you a very dense point cloud (more than 1 point per Sq.m), contours of 0.25m/0.5m can be generated.

As the present day Lidar systems generate a very dense point cloud, user community is using it for feature capturing and modeling as well. Vectorization of building edges, roads, transmission lines etc. is possible such high density LiDAR data set

In some of the recent practices, aerial photo acquisition will be carried out along with LiDAR mapping. This will help in generating orthophotos for the project area very quickly. Though not a common practice, LiDAR Intensity images can be used for generating an image using the LiDAR camera alone. As the pixel resolution of intensity image is not comparable with aerial camera results, to get a high quality image of the study area, aerial photo acquisition is required.

### **2.2 LiDAR Accuracies**

LiDAR accuracies depend upon the onboard GPS quality, LiDAR equipment frequency and angle, terrain and land cover condition. In general, the following accuracies can be expected:

- Vertical Accuracy: Bare Earth: 18.5 cm RMSE
- Vegetation: 37 cm RMSE
- Horizontal Accuracy: 1 meter RMSE
- For bare earth elevation models:
  - 89% of artifacts or more removed ;depending on terrain and vegetation
  - 90% of all outliers removed
  - 90% of all vegetation removed 93% of all buildings removed

### 2.3. Comparison between LiDAR & Aerial Photogrammetry

The following table (Table.2) list out the comparative features in both the technologies - LiDAR & Aerial Photogrammetry

Features	LiDAR	Photogrammetry
Energy source	Active	Passive
Geometry	Polar	Perspective
Sensor type	Point	Frame or Linear scanning
Point measurement	Direct	Indirect
Sampling	Individual points	Full area
Associated image	None or monochrome	High quality spatial and radiometric
Horizontal accuracy	2-5 times less than vertical accuracy	1/3 better than vertical accuracy
Vertical accuracy	10-15 cm (10 cm per 1,000 m over heights of 2,500 m)	Function of flying height and focal length of camera
Flight planning	More complex due to small strips and potential data voids	Overlap and side lap need to be considered
Flight restrictions	Less impact from weather, day/night, season, cloud condition	Must fly during day and need clear sky
Production rate	Can be more automated and faster	
Budget	25-33% of Photogrammetric compilation budget	
Production	Proprietary software: processing performed by vendors, operators	Desktop software available to end-user
Limited contrast area acquisition	Can acquire data: used extensively for coastal mapping	Difficult and expensive

Table.2.Comparison between LiDAR and Aerial Photogrammetry

### 3.0. High Resolution satellites for 3D applications

Most of the present day high resolution satellites have the capability of producing stereo images (Table.3). As the present day Photogrammetry software have the capability of reading stereo satellite imageries, we can create extremely detailed Digital Elevation Models (DEM) of approximately 3m – 5m resolution.

Satellites	Resolution	Positional Accuracy (CE90)	Flying Altitude	Swath Width	Stereo Availability
<b>GeoEye 1</b>	0.5 m Panchromatic 2.0 m Multispectral	2.5 m	684 kilometers	15.2 Km at Nadir	Yes
<b>IKONOS</b>	0.8 m Panchromatic 3.2 m Multispectral	15 m	680 kilometers	11.3 Km at Nadir	Yes
<b>QuickBird</b>	0.6 m Panchromatic 2.4 m Multispectral	23 m	450 kilometers	16.5 Km at Nadir	Yes
<b>WorldView1</b>	0.5 m Panchromatic	6.5 m	496 kilometers	17.6 Km at Nadir	Yes
<b>WorldView2</b>	0.5 m Panchromatic 2.0 m in Multispectral ( 8 band)	4.6 m to 10.7 predicted	770 kilometers	16.7 Km at Nadir	Yes
<b>Cartosat 1</b>	2.5 m Panchromatic		618 kilometers	26.8 Km at Nadir	Yes

Table.3. Typical high resolution satellite information

### 3.1. Stereo Image Generation and Vectorization

A methodology for the Satellite stereo generation involving Geoeeye stereo pair, run through the following steps:

- Load the images with their RPC's and set the GCP and output projection
- Collect Tie and pass points
- Collect Ground Control Point (GCP)
- Accuracy evaluation using both GCPs and Tie Points;
- 3D Feature collection (Fig.2)

The Geoeeye RPC model implemented in Rolta Photogrammetric Mapper has been used for some of our in-house projects. Using Geoeeye stereo satellite imagery, we were able to achieve Plainmetric accuracy of 0.2 m and Height accuracy of 0.3m.

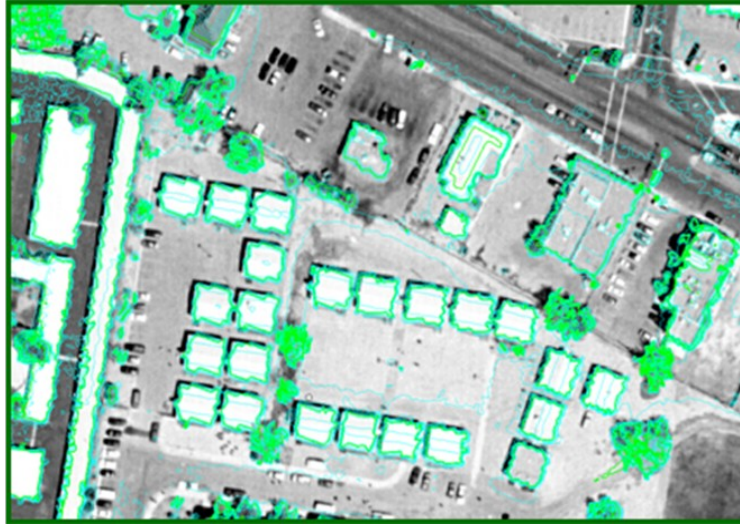


Fig.2. 3D Feature collection on Geoeye Stereo Satellite imagery

### 3.2. Resultant Products from Satellite stereo

Our experience on high resolution stereo satellite shows that it can be used for medium scale mapping. High resolution satellites such as geoeye1/worldview are capable of producing DEM that can be used for 2m contour generation. As the best pixel size that is available in such imageries is 0.5m, doing a detailed feature extraction mapping is still need to be evaluated. But to generate features for 1:7000 scales and above, such high resolution can still be used. Orthophotos that are mainly used as a picture map or for using 2D feature extraction can also be generated with a resolution of 0.5m or above.

### 3.3. Comparison between High Resolution stereo satellite image and aerial image

The RMSE achieved for Geoeye test data, shows that the Map Scale of 1:2000 (Fig.7) is achievable as per ASPRS standards reference, but the problem lies with the GSD of the satellite Data, for Geoeye has a GSD 0.5m

A target scale of 1:6000 and less is not possible with resolution 0.5 m as some of the finer features like poles, manholes will not be visible on these satellite images and therefore for such map scales Aerial imagery is used. With the present commercial stereo satellite imagery available a target scale of 1:6000 or more is possible as highlight in red in the table below (Table.4).

The table (Table.4) below shows the targets maps scales achievable using both Aerial imagery and Satellite Imagery.

<b>ASPRS Planimetric Feature Coordinate Accuracy Requirement (Ground X or Y) for Well Defined Points</b>								
<b>Target Map Scale</b>	<b>ASPRS Limiting RMSE in X or Y (Metres)</b>			<b>Target Map Scale</b>	<b>ASPRS Limiting RMSE in X or Y (Feet)</b>			
<b>Ratio m/m</b>	<b>Class 1</b>	<b>Class 2</b>	<b>Class 3</b>	<b>1"=X ft</b>	<b>Ratio ft/ft</b>	<b>Class 1</b>	<b>Class 2</b>	<b>Class 3</b>
1:500	0.125	0.25	0.375	40	1:480	0.4	0.8	1.2
1:1,000	0.25	0.50	0.75	50	1:600	0.5	1.0	1.5
1:2,000	0.50	1.00	1.50	60	1:720	0.6	1.2	1.8
1:2,500	0.63	1.25	1.9	100	1:1,200	1.0	2.0	3.0
1:3,000	0.75	1.50	2.25	200	1:2,400	2.0	4.0	6.0
1:4,000	1.0	2.0	3.0	300	1:3,600	3.0	6.0	9.0
1:5,000	1.25	2.50	3.75	400	1:4,800	4.0	8.0	12.0
<b>1:8,000</b>	<b>2.0</b>	<b>4.0</b>	<b>6.0</b>	<b>500</b>	<b>1:6,000</b>	<b>5.0</b>	<b>10.0</b>	<b>15.0</b>
<b>1:9,000</b>	<b>2.25</b>	<b>4.5</b>	<b>6.75</b>	<b>600</b>	<b>1:7,200</b>	<b>6.0</b>	<b>12.0</b>	<b>18.0</b>
<b>1:10,000</b>	<b>2.5</b>	<b>5.0</b>	<b>7.5</b>	<b>800</b>	<b>1:9,600</b>	<b>8.0</b>	<b>16.0</b>	<b>24.0</b>
<b>1:16,000</b>	<b>4.0</b>	<b>8.0</b>	<b>12.0</b>	<b>1000</b>	<b>1:12,000</b>	<b>10.0</b>	<b>20.0</b>	<b>30.0</b>
<b>1:20,000</b>	<b>5.0</b>	<b>10.0</b>	<b>15.0</b>	<b>1667</b>	<b>1:20,000</b>	<b>16.7</b>	<b>33.0</b>	<b>50.0</b>

Table.4. ASPRS Plainmetric Feature Coordinate Accuracy

#### 4.0. Comparison between LiDAR, High Resolution stereo satellite image and aerial image

The following table (Table.5) list out the comparative features in both the technologies - LiDAR, Aerial Photogrammetry and High Resolution stereo satellite image.

	Contour Interval	LiDAR	High Resolution satellite stereo	Aerial Photogrammetry/ Photo Scale
Contour Generation	0.5 m	✓		✓ (1:5000)
	1 m	✓		✓ (1:10000)
	2 m	✓	✓ Geoeye & Worldview (0.5m)	✓ (1:25000)
	5 m	✓	✓ Geoeye, Worldview & Ikonos (1m & below)	✓ (1:40000 & Above)
	10 & Above	✓	✓ (Many Satellites)	
	Target Map Scale			
3D Feature Extraction & Base Map creation	1:500	Feature Collection possible, but for Higher accuracy images are required		✓ (1:3500)
	1:1000			✓ (1:6000)
	1:2500			✓ (1:12500)
	1:5000			✓ (1:30000)
	1:7,500 & Above		✓ Geoeye & Worldview (0.5m)	✓ (1:40000 & above)
	Output Resolution			
Ortho Photo Generation	0.1 m	LiDAR alone will generate DEM's		✓ (1:5000)
	0.25 m			✓ (1:15000)
	0.5 m		✓ Geoeye & Worldview (0.5m)	✓ (1:30000)
	1 m		✓ Geoeye, Worldview & Ikonos (1m & below)	✓ (1:50000 & Above)
	2.5 m		✓ Geoeye, Worldview, Ikonos & Cartosat 1 (2.5m & below)	
	5m & Above		✓ (Many Satellites)	

Table.5. Overall comparison of three mapping technologies – LiDAR, High resolution stereo satellite image and Aerial image

## **5.0. Conclusions**

In this paper, we tried to compare three high end 3D mapping techniques.

Commercial LiDAR mapping systems that started in the early 2000s has shown a great potential in generating a high quality and accurate DEM generation. Though acquisition cost wise it may be at a higher side compared to aerial Photogrammetry, time, manpower and the achievable details makes it the best choice for DEM and contour generation.

High resolution stereo satellites are still under evaluation for detailed mapping. The most significant plus points of such datasets includes less no of images compared with aerial photos (minimizes triangulation time) and the flying restriction issues. Though it may not be a full replacement for traditional aerial Photogrammetry, medium scale mapping can be done with this technique. Feature extraction meeting 1:7000 scales and above can be done using satellite stereo technique.

## **6.0. Acknowledgements**

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