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BUREAU OF INDIAN STANDARDS

भारतीय मानक

हवाई लिडार डेटा अधिग्रहण - निर्दिष्टीकरण

Draft Indian Standard

Airborne LiDAR Data Acquisition Part 1 Requirements

BUREAU OF INDIAN STANDARDS

MANAK BHAVAN. 9 BAHADUR SHAH ZAFAR MARG

NEW DELHI -110002

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FOREWORD

To be added Later.

This Draft Indian Standard may be adopted by the Bureau of Indian Standards, after the draft finalized by Geospatial Information Sectional Committee had been approved by the Electronics and Information Technology Divisional Council.

LiDAR data have been used in research and commercial mapping environments for more than two decades. Advancements and improvements in instrumentation, software, processes, applications, and understanding are constantly refined or developed. It would not be possible to develop a set of guidelines and specifications that address all these advances. This standard is based on our understanding of and experience with the LiDAR technology being used in the industry at present. Furthermore, it is acknowledged that there is a lack of commonly accepted best practices for numerous processes and technical assessments (for example, measurement of Nominal Pulse Spacing (NPS), point distribution, classification accuracy, common accuracy and quality indicators, and others). Through its industry partners, other government agencies, and the appropriate professional governance organizations, the BIS fosters the creation of such best practices and considers them while revising this or any standard of similar nature in the future.

INTRODUCTION

India's geographical landscape encompasses a wide range of terrains, including vast plains, rugged Himalayan mountains, dense forests, coastal regions, and riverine networks. Each of these regions poses distinct challenges for LiDAR data acquisition and processing. Furthermore, the Monsoon climate, with its seasonal variations and intense rainfall, presents additional complexities. It is crucial to develop standards that account for these unique features to ensure accurate and reliable LiDAR data.

This standard presents the unique set of LiDAR mapping standards specifically developed for the diverse geography and topography of India. While existing standards from countries like the USA, New Zealand, and Canada serve as valuable references, it is imperative to address the distinctive challenges and requirements that arise from India's geographical and climatic conditions. This standard aims to provide comprehensive guidelines for LiDAR data acquisition, processing, and quality control that align with India's specific characteristics.

This standard acknowledges and addresses the challenges that arise during LiDAR data acquisition in India. Special consideration is given to factors such as the Monsoon climate, the rugged topography of the Himalayas, and the Western and Eastern Ghats. By recognizing and accounting for these challenges, we aim to optimize data acquisition methodologies and ensure accurate mapping results.

It shall be emphasized that this is a base specification, defining minimum parameters for acceptance of the acquired LiDAR data along with simultaneously captured photographic data. It is expected that local conditions in any given project area, specialized applications for the data, or the preferences of co-operators, may mandate more stringent requirements. It may be encouraged to collect more detailed, accurate, or value-added data. The appendix includes a list of common upgrades to the minimum specifications outlined in this report for some specific domains. It may be noted that the terms LiDAR/LiDAR Data/LiDAR survey employed in this standard also refers to Photograph/Photographic Data/Photographic Survey, if these are being captured simultaneously.

LiDAR technology is also used for specialized scientific research and other projects whose requirements are incompatible with the provisions of this specification. In such cases, and with properly documented justification supporting the need for the variance, waivers of any part or all of this specification may be considered. It is conceivable that in some cases, based on specific topography, land cover, intended application, or other factors, the clients may require specifications more rigorous than those defined in this standard.

Technical alternatives to enhance the delivery of data or associated products and processes as described by parameters and language in this standard are encouraged and may be submitted with any proposal and shall be given due professional consideration.

Structure of the standard:

The specifications presented in this standard are for various stages during a project. The following diagram presents a summary of these, and their respective stages.

Specifications for Aerial LiDAR Survey

Specifications for Data Acquisition

Specifications for Basic Collection Requirements:

Outlines the basic conditions/requirements and methods to meet the project requirement.

Specifications for Pre- Project Activities:

Lists the activities and their procedure before the beginning of actual data collection.

Specifications for data collection activity:

Outlines the guideline specifications to be followed during data collection.

Specifications for Data Quality Assessment:

Specifies the methods for quality assessment and their reporting.

Specifications for LiDAR Data deliverables:

Lists the schema for supply of various deliverables.

Specifications for LiDAR Data Processing:

Outlines the procedures to be adopted to process data captured for producing various deliverables.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’.

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INDIAN STANDARD

AIRBORNE LIDAR DATA ACQUISITION PART 1 REQUIREMENTS

1. Scope

This standard shall be used as a reference for aerial LiDAR data acquisition being carried out across India that involve the collection of elevation data along with aerial photographs. This standard provides:

a) Specifications for LIDAR Data Acquisition.
b) Activities and their procedure before the beginning of actual data collection.
c) Specifications to be followed during data collection.
d) Specifications for Data Quality Assessment.
e) Specifications for LiDAR Data deliverables.
f) Specifications for LiDAR Data Processing.

The specifications and guidelines mentioned in this standard are applicable to LiDAR data and deliverables provided by various data providers in India. These requirements aim to aid various agencies, whose work is to give technical advice to their implementing authorities, as well as to people and organizations in India who shall comprehend and make plans for the collecting of aerial LiDAR data.

2. References

The Standards listed in Annex A and Annex B contains provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated in Annex A and Annex B.

3. Abbreviations

Abbreviation	**Description**
ANPD	Aggregate Nominal Pulse Density
ANPS	Aggregate Nominal Pulse Spacing
AOI	Area of Interest
ASPRS	American Society of Photogrammetry and Remote Sensing
CORS	Continuously Operating Reference Stations
DEM	Digital Elevation Model
DGCA	Directorate General of Civil Aviation
DSM	Digital Surface Model
DTM	Digital Terrain Model
FOV	Field of View
GDOP	Geometric Dilution of Precision
GNSS	Global Navigation Satellite System
GPS	Global Position System
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
ISO	International Standard Organization
LAS	LASer file format exchange
LAZ	LASzip
LiDAR	Light Detection and Ranging
NPD	Nominal Pulse Density
NPS	Nominal Pulse Spacing
NSDI	National Spatial Data Infrastructure
NVA	Non-Vegetated Vertical Accuracy
PDOP	Position Dilution of Precision
$RMSE_x$	Root Mean Square Error in the *x* direction (easting)
$RMSE_y$	Root Mean Square Error in the *y* direction (northing)
$RMSE_r$	Root Mean Square Error in the radial direction (includes both x and y directions)
$RMSE_z$	Root Mean Square Error in the vertical (z direction or elevation)
$RMSD_z$	Root Mean Square Difference in the z direction (elevation)
SRTM	Shuttle Radar Topography Mission
TIN	Triangular Irregular Network
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VVA	Vegetated Vertical Accuracy
WGS	World Geodetic System
XML	eXtensible Markup Language

4. Data Acquisition

4.1 Basic Collection Requirements:

4.1.1 Units of reference

All references to the units of measure shall be in the SI system. The base unit of angle shall preferably be in degrees while in some cases as per practice it will be in radian.

4.1.2 Datum and projection

National Spatial Reference Frame (based on WGS84 ellipsoid and datum) established by the Survey of India through well-distributed ground control points/CORS shall be used for capturing the data. The map projection system or map coordinate system can either be in geographic coordinates (longitudes and latitudes), or UTM map projection coordinates (Easting and Northing).

To convert the 3D data to any local topocentric coordinate system with a specific datum, standard processes for establishing the local network and coordinate and datum transformation shall be followed.

For conversion of ellipsoidal height to orthometric height, the geoid model developed by Survey of India and/or levelling benchmarks provided by Survey of India shall be used.

4.1.3 Area of interest

a) Surveying of areas

The area of interest (AOI) has to be described as a polygon with its vertices expressed in the specified projection or coordinate reference system.

A buffer around the AOI is recommended to be in the range of 100 – 300 m. (*See* Note 1)

NOTE[1] **- Additional requirements for simultaneous photographic data acquisition:**

A buffer of 100 times the ground sampling distance (GSD) or the range of 100 – 300 m, whichever is more, shall be provided.

It shall be mentioned whether or not the AOI includes the buffer.

b) Surveying of corridors

In the case of corridor projects (railway lines, highways, power lines, canals etc.,) a buffer of 5% of the total corridor width or 100 m, whichever is smaller, on either side of the corridor is recommended.

The AOI shall be given in the same horizontal and vertical datum as that of the survey. The best and most accurate available records shall be used to define the AOI. If no proper records of AOI are available, it is advisable to conduct a rapid recce to obtain an initial estimate of the AOI.

4.1.4 Information about topography

General information about the geology and geomorphology of the area may be supplied by the data user, if available. The digital elevation model (DEM) derived from SRTM data or SoI toposheets, photogrammetric information or any other reliable source may be provided. The vertical datum of the DEM shall also be mentioned.

4.1.5 Data collection conditions

a) Survey season

It is advisable to conduct the aerial survey in the leaf-off season and avoid monsoon periods. The cloudy sky condition leading to shadows shall be avoided. In most parts of the country, the monsoon or rainy season lasts from June to early September, some parts like Tamil Nādu and Kerala have a slightly different monsoon season. The same must be studied carefully during the Mission Planning stage.

The leaf-off season that occurs between September and October, in North India, shall be preferred. Late November to January shall be avoided for aerial survey due to more smog in the atmosphere, unless visibility is normal.

The following sources can be utilized to obtain long and short term weather forecast information,

i. India Meteorological Department, Ministry of Earth Sciences publishes all kinds of weather forecast information through their websites for all parts of the country.
ii. Every major airport has their dedicated meteorological departments, which can provide us with crucial information about the local weather.

b) Atmospheric conditions:

The atmosphere shall ideally be free of cloud, smog, haze and fog between the aerial platform and ground during all aerial data collection operations.

i. Atmospheric haze or fog

Fog is composed of a large number of tiny water droplets or ice crystals that are suspended in near-surface air.

Haze is a large number of tiny dry dust particles floating uniformly in the air.

LiDAR data capture shall be avoided in case of medium to heavy fog.(*See* Note 2)

NOTE[2] - If visibility is less due to haze/fog, avoid photograph capture.

ii. Clouds

There shall not ideally be any clouds between the ground and the aerial platform during LiDAR capture (*See* Note 3)

NOTE[3]- Clouds above the aerial platform will create shadows in the photographs. As a rule of thumb avoid photograph capture when

a. There is 30-40% cloud cover above the platform.
b. There are shadows on more than 5% of an image.

iii. Wind

Ideally, data shall be captured when there is no wind. However, a maximum wind speed of 10.29 m/s (20 knots) at flying height is allowable for airborne

data acquisition. In the presence of wind, flight shall be conducted either in headwind or tailwind directions only but not in the case of crosswind.
In some specific conditions, higher wind speeds can also be tolerated with appropriate measures to ensure good data quality.

iv. *Sun angle and time of the day*

LiDAR data acquisition is independent of the sun's illumination and time of the day. (*See* Note 4)

NOTE[4] - For simultaneous optical photographic data acquisition, the period in a given day shall be explicitly mentioned in the requirement specifications. In general, it is recommended that it shall be within two hours on either side of the local noon (i.e., local noon time ±2 hours).

To minimize the shadow in the aerial photographs, the sun elevation angle shall be more than 30º at all times. Taking aerial photography in urban territories is better at midday when shadows are shortest and the following conditions are mandatorily considered,

1. The amount of tilt in buildings and other raised features that obscure ground detail.
2. The obstruction of transportation features by buildings or shadows.
3. The obstruction of features in the interior of a city block by tall buildings.

The clipping of features (for example, radio towers, water tanks, buildings) at photograph file boundaries.

c) Snow conditions

It must be snow-free. Very light and non-drifted snow may be acceptable in areas where snowfall is a common event. Collections for specific scientific projects may be exempted from this requirement with appropriate understanding.

d) Water conditions

For the collection of elevation data, it's essential to ensure that the ground is not abnormally flooded or inundated. However, if the aim is to map the flooded regions, the data can be collected during the flooding condition. While capturing floodplain and wetland data, it's necessary to do it during the base flow and outside of significant surface inundation caused by natural events or regulated environmental flows. In the case of Coastal surveys, the data shall be gathered within two hours of low tide on either side to decrease the influence of standing water or wave action.

e) Vegetation conditions

Although leaf-off vegetation conditions are ideal for collecting elevation data, it's not always possible to control all the factors that affect vegetation condition during the data collection process. Therefore, it's necessary to ensure that the laser used can penetrate to the ground and produce an accurate and reliable bare-earth surface. However, certain scientific research projects may be exempted from this requirement if appropriate understanding and documentation is in place.

f) Weather:

All flights shall be conducted under rain-free conditions. Adequate gaps shall be given after rain to allow the water to drain off.

4.1.6 Data requirements

a) Accuracy

The planimetric and altimetric absolute accuracies shall be specified. Accuracy measures shall be measured as Root Mean Square Error (RMSE). For likely values of accuracy measures /error measures, the reader shall refer to the latest literature available in this area.

b) Relative vertical accuracy

Relative vertical accuracy shall also be specified. Relative accuracy requirements for within a swath and within swath overlap shall be achieved according to the specified values. The following guidelines are proposed:

i. within individual swaths on flat surfaces (strips): $\sigma_z \leq 7$ cm
ii. Within swath overlap between adjacent swaths (strips): $\sigma_z \leq 10$ cm.

NOTE[5]: σ_z is the standard deviation of the altimetric values of the LiDAR data points corresponding to the test site situated in flat and plain areas.

c) Overlap

A swath overlap of 10% or greater, is required to ensure that there are no data gaps between the usable portions of swaths and also to improve internal /relative accuracy of scan data. Collections of elevation data in high-relief terrain shall require greater overlap. Any data with gaps between the geometrically usable portions of the swaths shall not be accepted.

d) Data density

The minimum data density required in the project shall be specified. Data density can either be specified in points/m^2 or nominal pulse spacing (NPS). As such there are no mandatory rules, however Table 1 provides a guideline for projects about different applications. Specifications for specific projects are given in Appendices A, B, and C.

NOTE[6]: $NPS = \frac{1}{\sqrt{\text{Data Density}}}$

Collections designed to achieve the NPS through swath overlap or multiple passes are generally discouraged. Such collections may be permitted with prior understanding / agreement.

Table 1: The recommended ANPD and GSD for application-specific uses of LiDAR data in various disciplines.

Discipline	Application	Recommended ANPD (points/ m^2 -- Indicative range	Nominal GSD of raw image (m) -- Indicative range

Urban Planning	City Mapping (to cater to all urban applications)	25-40	0.05-0.25
	Building Classification	10-40 (10-15: for large buildings, and 15-40: for small buildings)	0.07-0.10
	Urban Morphology and Green Analysis	14-20	0.10-0.50
	Mapping Power Transmission Lines (Low and High voltages)	25-50	--
	Airport Applications	25-50	0.50-0.80
	Solar Radiation Assessment (roof area mapping)	10-40	0.20-0.50
Forestry	(A) Tree Species Identification, (B) Vegetation Characterization	10-30	0.05-0.10
	(A) Forest Measurement and Monitoring (B) Tree Height Measurement	5-10	
	DEM Accuracy under Canopy Cover	10-30	
	Biomass Stocks and Change Estimation in Forest Cover	15-30	
	Fire Loads	10-15	0.10-0.50
	Mapping Burns	5-10	
Irrigation	(A) Irrigation System Design (good quality DEM) (B) Irrigation System Monitoring	10-30	0.05-0.08
Land Record Management	Bund System Design	25-40	0.05-0.10
Hydrology	Urban Flood	25-40	0.20-0.50
	Riverine Flood	6-10	0.50-1.00
	Coastal Floods	6-10	0.20-0.50
	Special Zones	25-40	0.10-0.30
	Water Harvesting Site Selection	10-30	0.10-0.30

Rail Corridor	Ground Survey for High-Speed Rail Corridor (Plain Terrain)	35-50	0.05-0.07
	Ground Survey for Rail Corridor (Hilly Terrain) - FLS case	15-20	0.10-0.20
Power Corridor	Catenary System Detection, Localization and Classification	25-40	
	Overhead Catenary System Inspection	25-40	0.10-0.20
Roads and Highways	Road Network Mapping and Planning	15-30 (mapping of existing roads), 15-20 (survey for new road construction)	0.05-0.20
Geology	Landslide Mapping and Monitoring	10-30	0.10-0.30
	Coastal Erosion	6-10	
	Morphology	6-10	
Mining	Subsidence Mapping	5-10	0.15-0.30
	Open Pit Mines Mapping	5-10	
Archaeology	Open areas (heritage site detection/ identification)	25-40	0.05-0.20

e) Comparable point spacing

Average along-track and cross-track point spacing shall be comparable (within 10 per cent).

f) Data voids

Data Voids (areas ≥ 4 NPS^2) measured using first returns only within a single swath, shall not be present except:

i. where caused by water bodies,
ii. where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing, or
iii. where appropriately filled-in by another swath.

Data voids in areas except the above can be filled by an alternate method (GNSS, Total station, Drone, etc.) provided:

i. This is mutually agreed between the data user and data provider.
ii. The alternate method gives data with the same specifications
iii. Aggregate of such voids is less than 1% of project area.
iv. The alternate data are captured within 15 days of the LiDAR survey.

g) Additional Requirements for Simultaneous photographic data acquisition

i. **Photograph capture format**: The format for capturing the photograph (large, medium or small) shall be specified according to the state-of-art definitions of photograph formats.

ii. **Photograph color band information:** Photograph colour band information viz. red-green-blue (RGB), panchromatic (PAN), or color infrared (CIR), shall be specified.

iii. **Sidelap and endlap**: The amount of sidelap and endlap in percentage terms shall be specified. In general, it is recommended that the minimum sidelap shall be in the range of 25 – 40% and the minimum endlap shall be 60%. In the case of true ortho-photographs a minimum overlap of 80% endlap and 60% sidelap shall be there.

iv. **Orthophoto-image relationship:** The values of the nominal ground sampling distance (GSD) of the raw photographs and the ground sampling distance of the ortho - photographs (GSD_{ortho}) shall follow the rule in Equation 2.1.

$$GSD_{\text{ortho}} \geq 1.13 \times GSD \qquad (1.1)$$

v. **LiDAR sensor and camera FOV relationship:** The across-track FOV of the airborne digital frame camera and half scanning angle of the LiDAR scanner shall follow Equation 2.2.

$$(1-P_e)\tan\phi_{\max} \leq (1-P_{ecy})\tan\left(\frac{\phi_{opt}}{2}\right) \qquad (1.2)$$

where,

$\phi_{\max}$ – maximum allowable value of half scanning angle of the LiDAR scanner

P_{ecy} – minimum percentage sidelap for photograph data

P_e – minimum percentage value of LiDAR flightline overlap

ϕ_{opt} – across-track FOV of camera

Example: For a 44° across-track FOV of the camera, 25% sidelap, and 10% minimum LiDAR flightline overlap, Equation 2.2 calculates the value of maximum half scanning angle as 18.6°.

NOTE[7]: This requirement is primarily applicable to scanners with Palmer, rotating or oscillating mirror arrangement (where the single-point emitter creates a rectangular swath on the ground surface and forms a triangle with the swath line). Other instrument technologies may use other appropriate method.

4.1.7 Aircraft and crew

a) The aircraft shall be maintained and operated in accordance with the regulations of the DGCA.
b) The selected aircraft shall be able to perform adequately for the satisfactory completion of the entire project.
c) Appropriate mount and POD have to be used in order to avoid vibrations. Even a small quantity of aircraft vibrations can cause significant distortions in the data sets that are being captured.

d) Care shall be given when planning the aerial survey missions with pressurized aircrafts. The camera window in a pressurized aircraft is usually covered by an optical-grade glass plate. In the case of a high-altitude flight, the glass plate will be deformed and distorted, caused by the difference between the cabin and outside air pressure.

Measurements made by Dr.-Ing. H.K.Meier and Dr. rer.nat. Zuegge(Carl Zeiss, Oberkochen) state that the glass plate must have these dimensions in order to avoid distortions caused by a "twisting" of the glass plate:

Table 2: Dimensions of glass window in order to minimize the twisting effect

Dimensions of glass window in order to minimize the twisting effect		
Lens type	Diameter of glass(m)	Thickness of glass(m)
0.085 m	0.720	0.045
0.153 mm	0.420	0.030
0.305 mm	0.256	0.020
0.120 mm (DMC)	0.400	0.030

These dimensions ensure a distortion of less than 2 µm

(Reference: "High Altitude Flights Using Aerial Survey Camera Systems" by Aerial Survey Base)

The thickness and the diameter of the glass must be studied carefully which shall not affect the performance of any sensors.

e) The mount/any modifications made in the aircraft shall be in accordance with DGCA regulations and approval.
f) In some fixed-wing aircraft, the exhaust gases from the engines might create disturbances in photograph, this shall be avoided at all costs (by installing an extension).
g) It is advisable to use pilots with at least 50 hours of prior flying experience for aerial survey missions to avoid inaccurate flying which will create gaps between lines .
h) The Airborne Sensor Operators are equally important in any aerial survey mission, so it is advisable to train them properly, organizations like "Airborne Sensor Operators Group" have published guidelines for Airborne Sensor Operators, the same can be referred.
i) A standard SOP, checklist and data log sheet have to be maintained at all times.

4.1.8 LiDAR *s*ensor requirements

The laser sensor must be capable of:

a) detecting multiple returns, with a minimum of 4 potential returns for each outbound laser pulse,
b) recording the intensity of each return, and
c) full waveform collection (over and above discrete returns) – *optional.*

i. Aerial camera specifications

Shall have Forward Motion Compensation

Aerial camera of any format (small, medium and large)

The Ground Sampling Distance (GSD) of an aerial photographs can be calculated as $GSD = \frac{Px}{f} \times h$

where, P_x is the pixel size in CCD

f is the focal length

h is the altitude

GSD Calculator by Aerial Survey Base is a useful tool.

ii. Inertial measurement unit

The minimum configuration is recommended below:

Gyro Bias <0.05º/h or better

Data Rate >100 Hz or better

Roll Pitch Accuracy better than 0.005º

Heading Accuracy better than 0.008º

Velocity Accuracy better than 0.007 m/s

iii. GNSS unit

Optional Dual Antenna hardware, minimum 336 channels for simultaneous tracking of all visible supported satellite signals

GPS	L1C/A, L1C(Optional), L1P(Y) (Optional), L2C, L2P/E, L5
GLONASS	L1C/A, L2C/A, L2P(Optional), L3
Beidou	B1, B1C, B2a, B2
Galileo	E1, E5a, E5b, E5 AltBoc, E6 (optional)
QZSS	L1C/A, L1C, L2C, L1 SAIF (Optional), L5, LEX/L6 (Optional)
NavIC	L5, S(optional)
SBAS	L1 C/A, L5

The onboard GNSS device shall have any of the appropriate positioning modes with the below-mentioned accuracy levels in order to be able to produce results within the required project accuracy.

Positioning Mode	Horizontal Accuracy (RMS)	Vertical Accuracy (RMS)
RTK	1 cm + 1 ppm	1.5 cm + 1 ppm
Single Point	1.5 m	3 m
SBAS	0.6 m	0.9 m
DGNSS	0.4 m	0.6 m
PPP	4 cm	6 cm
Post-Processed	2 cm	5 cm

Minimum Measurement Rate: 5 Hz

5. Data Quality Assessment

This Clause describes the procedures for assessing and verifying the various data requirements mentioned in *Clause* 4.

5.1 Altimetric accuracy

Altimetric or vertical accuracy is a function of $RMSE_z$ (root mean square of the altimetric errors). There are three alternatives to reporting altimetric accuracy depending upon the land cover/land use class and statistical distribution of altimetric error. It is recommended that selected sites for quality assessment (QA) shall be flat and horizontal as well as located at the areas of minimum elevation, as far as possible.

5.1.1 Absolute vertical accuracy

a) The absolute vertical accuracy of the LiDAR data and the derived DEM will be assessed and reported in accordance with ASPRS (2014).
b) Vegetated and non-vegetated land cover types shall be assessed for absolute vertical accuracy.
c) Four absolute accuracy values shall be assessed and reported:
   i. NVA for the point data.
   ii. VVA for the point data.
   iii. NVA for the DEM.
   iv. VVA for the DEM.

   NVA will be assessed for open areas that result in single returns.

   VVA will be assessed for vegetated areas that result in multiple returns.

d) The minimum NVA and VVA requirements for all data, using the ASPRS methodology, are listed in Table 3. Both the NVA and VVA required values shall be met.

e) NVA for the point data shall be assessed by comparing check points that are surveyed for NVA assessment of a triangulated irregular network (TIN) constructed from ground-classified LiDAR points in those areas.

f) VVA for the point data shall be assessed by comparing check points surveyed for VVA assessment to a triangulated irregular network (TIN) constructed from ground-classified LiDAR points in those areas.

NVA and VVA for the DEM are assessed by comparing check points to the final bare-earth surface

Table 3: Absolute vertical accuracy for light detection and ranging data and digital elevation models

Quality level	**RMSEz (non-vegetated) (m)**	**NVA at the 95-percent confidence level (m)** **1.96 * $RMSE_z$**	**VVA at the 95th percentile (m)**
QL0	≤0.050	≤0.098	≤0.15
QL1	≤0.100	≤0.196	≤0.30
QL2	≤0.150	≤0.294	≤0.45
QL3	≤0.200	≤0.392	≤0.60

5.1.2 Procedure of assessing $RMSE_z$

$RMSE_z$ shall be determined using check points on available land cover/land use classes. The most common land cover categories are as follows:

a) Open terrain (sand, rock, dirt, ploughed fields, lawns, golf courses).
b) Urban areas with dense man-made structures.
c) Tall weeds and crops.
d) Brush lands and low trees.
e) Forested areas fully covered by trees.

The classes 1 and 2 shall be used for NVA while others for VVA.

Guidelines on selecting check points and calculating the $RMSE_z$ are provided below:

i. In a given AOI, there shall be one test site every 50 km^2. In a single test site, for each class, 20 checkpoints shall be selected. For example, if a project site is 1000 km^2, of which 400 km^2 is covered by classes 1 and 2 and rest by classes 3 to 5, there shall be 8 test sites for classes 1 and 2 and 12 test sites for classes 3 to 5 . Each test site will have a minimum of 20 checkpoints.

NOTE[8]: It is not an advisable practice to collect an abundance of checkpoints and retain only the best for vertical accuracy reporting.

ii. Test sites must be established to adequately cover the full extent of the survey area (AOI) and be representative of the project area landscape. In a given rectangular test site, where uniform positional accuracies are expected, the distance between the checkpoints shall not be less than 10% of the diagonal length of the test site. Moreover, each quadrant of the rectangle shall contain at least 20% of the total check points lying in the rectangular area.

iii. The proposed check point survey design must be agreed upon, prior to implementation. Acceptance of the post-survey spatial accuracy report discussed above will depend on the quality, number and distribution of these check points.

iv. The checkpoints shall be measured with accuracies better than three times the desired accuracy of the LiDAR data using any other 3D data acquisition technique (GNSS, Photogrammetry etc.) OR existing maps.

v. $RMSE_z$ of the data shall be determined by creating a triangulated irregular network (TIN) of the ground class LiDAR data points after filtering out the outliers.

Using the planimetric coordinates of the check points and the TIN, the *z*-coordinate of the location shall be determined as Z_i. Since Z_i^{ref} of the checkpoint is already known, Equation 3.2 shall be used to determine the vertical accuracy.

$$\mathrm{RMSE}_z = \sqrt{\frac{\sum_{i=1}^{n} (Z_i - Z_i^{ref})^2}{n}} \qquad (1.3)$$

where,

n – number of check points,

Z_i – elevation data of i^{th} check point,

Z_i^{ref} – elevation data of i^{th} reference point.

5.1.3 Specifications for reporting vertical accuracy

The LiDAR datasets requires NVA, which is the vertical accuracy in open terrain tested to 95% confidence interval (for normally distributed error). It shall be specified, tested and reported. If no distinction is made when a document refers "vertical accuracy", it shall be assumed to be NVA vertical accuracy.

If information is required on the vertical accuracy achieved within other ground cover categories outside open terrain, then VVA must be considered. VVA is vertical accuracy tested using the 95^{th} percentile method (not necessarily normally distributed). It shall be specified, tested and reported for land cover class where multiple returns occur.

If contour maps or similar derivative products are to be generated across an entire project area, the project-wide vertical accuracy requirement shall be the same as listed in Table 4 across all land cover classes. This means that vertical accuracy in such cases shall be specified, tested and reported for each land cover class, reporting NVA in open terrain and a VVA in vegetated land cover class, each of which must independently meet the requirements for the desired contour interval.

Table 4: Relationship between $RMSE_z$, $accuracy_z$ and contour interval

Contour interval (m)	$RMSE_z$ (m)	$Accuracy_z$ (m)	Required accuracy of check points (m)
0.1	0.03	0.06	0.02
0.2	0.06	0.12	0.04
0.3	0.09	0.18	0.06
0.4	0.12	0.24	0.08
0.5	0.15	0.30	0.10
1.0	0.30	0.60	0.20
2.0	0.60	1.20	0.40
3.0	0.90	1.80	0.60
4.0	1.20	2.40	0.80
5.0	1.50	3.00	1.00

In some circumstances, it may be preferable to specify a different vertical accuracy for different land cover classes, specifying a relaxed vertical accuracy in forested areas, for example, then in agricultural fields. Such situations shall be explicitly stated in the project specifications.

It is commonly accepted that vertical accuracy testing in very irregular or steep sloping terrain is inappropriate due to the high probability that the error in the testing process is a significant contributor to the final error statistic and thus biases the results. For example, a small but acceptable horizontal shift in the data may reflect in an unacceptable vertical error measurement. Because of this concern, it is recommended that vertical accuracy testing always be done in areas where the terrain is as level and consistent as possible. In mountainous areas, level areas may not be easy to access, but attempts shall be made to keep test points on reasonably low slopes and smooth terrain as possible.

Note that for the specific case of contour mapping, extrapolating an NVA across different land cover classes with the assumption the vertical accuracy will meet the stated mapping standard, is not allowed. For example, if a dataset is reported with an NVA that just meets the vertical accuracy requirement listed in Table 4 for the desired contour interval, it is probable that it will not meet that mapping standard outside of open terrain.

For legacy datasets for which only a "vertical accuracy" was reported with no indication if this is NVA or VVA, it could be assumed that this is NVA, and it shall be used with caution when working with the dataset in different land cover classes. If possible, review the QA data and re-test the data to measure VVAs (95^{th} percentile testing) in areas outside open terrain.

5.2 Planimetric accuracy

Planimetric accuracy ($Accuracy_r$) shall be reported at 95 percent confidence level as: $Accuracy_r = RMSE_r \times 1.7308$. It is recommended that selected sites for QA shall be located at the areas of minimum elevation, as far as possible.

5.2.1 Planimetric RMSE

Since the method for determining $RMSE_r$ has not been explicitly mentioned in the literature, the $RMSE_r$ shall be confirmed using the LiDAR data points corresponding to the corners of buildings. The test sites for determining $RMSE_r$ shall be spread across the study area and could be same as those used for vertical RMSE. $RMSE_r$ can also be computed using the field observed coordinates of well-designed targets which can also be identified in LiDAR point cloud with or without the use of intensity data.

5.3 Relative vertical accuracy

For evaluating relative accuracy, standard deviation of LiDAR data σ_z shall be calculated specifically for flat areas which lie in single swath and swath overlapping areas. σ_z shall be less than or equal to the user specified values. It is recommended that selected sites for QA shall be located at the areas of minimum elevation, as far as possible.

5.4 Validation of NPS and data density

For unbiased estimate of NPS the following method is prescribed:

a) Construct a Delaunay triangulation using the planimetric coordinates of the LiDAR points.
b) Calculate the planimetric distance of every edge connecting one point to a neighboring point.
c) Calculate the average of the edge lengths and assign it to that point as a 'spacing value'.
d) If p_i be a point in the LiDAR dataset containing N points, let 'spacing value' corresponding to p_i be denoted by s_i.
e) Determine the 95th percentile value (S_v) of the set $\langle s_i \rangle_{i=1}^{N}$. Therefore, at least 95% of the points have NPS better than S_v for the LiDAR data to meet the NPS requirements.

The data density for each point can be estimated by:

i. Construct a Voronoï diagram using the planimetric coordinates of the LiDAR points.
ii. Calculate the area of the Voronoï polygons for each point.
iii. Assign the inverse of area value, or density in terms of points per unit squared, to the point.
iv. If $\mathbf{p}_i$ be a point in the LiDAR dataset containing N points. Let a_i be an inverse of area of the polygon for point p_i.
v. Determine the 95th percentile value (A) of the set $\langle a_i \rangle_{i=1}^{N}$. Therefore, at least 95% of the points have data density better than A.

NOTE[9]: Both the above exercises, for estimating NPS and data density can be performed for a single class, multiple classes or the entire dataset. However, it shall be reported accordingly.

f) Additional requirements for simultaneous photographic data acquisition:

GSD of a photograph is equivalent expression of the NPS of LiDAR data. It is recommended that selected sites for QA of GSD shall be located at the areas of minimum elevation, as far as possible

5.5 Overlap

LiDAR data overlap shall occur at the edges of the adjacent swaths. The overlap area can be confirmed by simultaneously displaying the data points of two adjacent swaths using any commercial or open source software display engine with capabilities of measuring the dimensions of the overlap area. Minimum overlap specifications shall be confirmed at the point of maximum elevation.

NOTE[10]- Additional QA requirements for simultaneous photographic data acquisition:

Quality assessment shall be done for overlap (endlap and sidelap) and possibility of occurrence of missing data / frames. For endlap and sidelap, the test sites shall be selected at the locations of maximum elevation.

5.6 Data voids

The statistics of data voids (area$\geq$ 4 NPS^2), e.g., their number, total area of data voids , their spatial distribution shall be determined using a software. Justification of data voids shall be generated by their overlap with a land use cover map.

5.7 Spatial distribution

The spatial distribution of geometrically usable points is expected to be uniform. Although it is understood that LiDAR instruments do not produce regularly gridded points, collections shall be planned and executed to produce the first-return point cloud that approaches a regular lattice of points, rather than a collection of widely spaced high density profiles of the terrain. The uniformity of the point density throughout the dataset is important and will be assessed using the following steps:

a) A regular grid, with cell size equal to the design 2×NPS will be laid over the data. Assessment to be made against single swath, first return data located within the geometrically usable center portion (typically 90%) of each swath.
b) At least 90% of the cells in the grid shall contain at least one LiDAR point.
c) Acceptable data voids identified previously in this specification are excluded.

NOTE[11]: This requirement may be relaxed in areas of substantial relief where it is impractical to maintain a consistent and uniform distribution.

6. LiDAR Data processing and Deliverable Data

6.1 Processing of point cloud data

All processing of point cloud data shall be carried out with an understanding that all point deliverables are required to be fully compliant with the ASPRS LAS Specification Version 1.4 (see Clause 7 for details). Data producers are encouraged to review the LAS specification in detail.

6.1.1 Use of the LAS withheld bit flag

a) The withheld bit flag, as defined in LAS specification version 1.4–R15 (ASPRS, 2014), shall only be used to identify points that cannot be reasonably interpreted as valid surface returns, for example, outliers, blunders, geometrically unreliable points, aerosol back-scatter, laser multi-path, airborne objects, and sensor anomalies.

b) The withheld flag may be used in conjunction with other classification codes (low/high noise for example), but it shall be used in all cases where the previously mentioned criteria are met.

6.1.2 Use of the LAS overlap bit flag

The overlap flag shall not be used for LiDAR point clouds unless requested by the data user. However, if overlap points are explicitly identified using LAS v1.4, they shall be identified using the overlap flag.

6.1.3 Classification

Classification of point cloud data shall adhere to the scheme recommended by ASPRS (see Table 5). The LiDAR point classes to be delivered according to this scheme are defined by the classification level specified in Table 5.

Table 5: Classification scheme for LiDAR point clouds

Value	Point Class	Description
0	Unclassified	Created, never classified
1	Default	Unclassified
2	Ground	Bare ground
3	Low vegetation	0 – 0.3m (essentially sensor noise)
4	Medium vegetation	0.3 – 2m
5	High Vegetation	> 2m
6	Building’s Structure	Buildings, houses, sheds, silos etc.
7	Low Point (Noise)	Spurious low point returns
8	Reserved	
9	Water	Any point in water
10	Rail	
11	Road Surface	
12	Reserved	
13	Wire – Guard (Shield)	e.g. ground wires structure
14	Wire – Conductor (Phase)	
15	Transmission Tower	
16	Wire-structure Connector	e.g. Insulator
17	Bridge Deck	
18	High Noise	
19	Overhead Structure	e.g., conveyors, mining equipment, traffic lights
20	Ignored ground	typically breakline proximity
21	Snow	if present and identifiable
22	Temporal exclusion	Features excluded due to changes over time between data sources – e.g., water levels, landslides, permafrost
13-63	Reserved	
64-255	User definable	

a) Restrictions on point classification

i. All the points, which are not flagged as withheld and fall within the classification scheme (Table 5) shall be properly classified.
ii. No points in the classified LAS point cloud deliverable may remain assigned to Class = 0 unless these points are flagged as withheld.
iii. No classification code may be used to identify points as overlap point.
iv. Points classified as water will only be checked when associated with a breakline
v. If overlap points are required to be differentiated specifically as one of the requirements of the project, they shall only be identified using the overlap flag, as defined in LAS v1.4.
vi. Any other techniques as mutually agreed upon.

b) Classification accuracy

It is required that due diligence in the classification process will produce data that meet the following test:

i. Within any 1 km × 1 km area, no more than 2 percent of non-withheld points shall possess a demonstrably erroneous classification value. This includes points in Classes 0 and 1 that shall correctly be included in a different Class required by the project.

In most circumstances, detailed visual inspections of individual classified scan line profiles and use of high-quality reference imagery will be sufficient to independently demonstrate if classification standards have been achieved for the specified classes.

The Data producer shall report on how classification accuracy is checked and assured.

NOTE[12]: Relaxations on classifications for difficult areas may be agreed upon by the data supplier and data consumer.

c) Classification consistency

Point classification is to be consistent across the entire project. There shall not be the noticeable variations in the character, texture, or quality of the classification between tiles, swaths, flights, or other non-natural divisions.

d) Levels of classification

The classes required for the LiDAR point clouds and their classification levels L1 to L4 shall be clearly specified by putting a tick mark in the respective boxes in Table 6, by the project authority. The table can be extended for more number of classes as required in a project but not listed in the table.

Table 6: Required levels of classification

ID	Point Class	Required classes	Classification Level Required (Specified accuracy range in %) L1 (<90)	L2 (90-95)	L3 (95-98)	L4 (>98)
1	Default	☐	☐	☐	☐	☐
2	Ground	☐	☐	☐	☐	☐
3	Low vegetation	☐	☐	☐	☐	☐
4	Medium vegetation	☐	☐	☐	☐	☐
5	High vegetation	☐	☐	☐	☐	☐
6	Buildings / Structures	☐	☐	☐	☐	☐
7	Low Point (Noise)	☐	☐	☐	☐	☐
9	Water	☐	☐	☐	☐	☐
10	Rail	☐	☐	☐	☐	☐
11	Road Surface	☐	☐	☐	☐	☐
13	Wire – Guard (Shield)	☐	☐	☐	☐	☐
14	Wire – Conductor (Phase)	☐	☐	☐	☐	☐
15	Transmission Tower	☐	☐	☐	☐	☐
16	Wire-structure Connector (e.g. Insulator)	☐	☐	☐	☐	☐
17	Bridge Deck	☐	☐	☐	☐	☐
18	High Noise	☐	☐	☐	☐	☐
19	Overhead Structure	☐	☐	☐	☐	☐
20	Ignored ground	☐	☐	☐	☐	☐
21	Snow	☐	☐	☐	☐	☐
22	Temporal exclusion	☐	☐	☐	☐	☐

6.2 Derivatives from LiDAR data

a) Some LiDAR deliverables can be in the form of images generated by interpolation of LiDAR data.

b) Derivable image files shall be in a lossless or no compression format. As a general guideline GeoTIFF is recommended.

c) The grid sizes of all image derivatives shall be clearly specified. As a general guideline, the grid cell size shall not be less than the ANPS of the LiDAR data.

d) All image derivatives shall be accompanied with georeferencing information, either embedded in the header or accompanied by a world file.

e) Void areas (for example area outside the project boundary but within the project tiling scheme) shall be coded using a unique “NODATA” value.

f) Data shall be delivered in tiles. For details see Clause 7.

6.2.1 Intensity images

a) Only the first return LiDAR points shall be used to generate intensity images.
b) In specific cases, as advised by data user , other returns can also be used .
c) The interpolation technique for calculating the value of a pixel of the intensity image shall be specified. As a general guideline, k-nearest neighbors (k-NN) or natural neighbors interpolation technique is recommended, or the interpolation technique specified by the user shall be used.

6.2.2 Digital surface model

a) Only first return LiDAR data shall be used to compute the digital surface model (DSM).
b) The algorithm for generating the DSM shall first convert the points to a Triangulated Irregular Network (TIN) and then convert the TIN to a raster of the given cell size. The raster computation process shall use one of the following interpolation techniques or user-specified interpolation technique. A few suggested methods are as follows:
   a) k-nearest neighbors
   b) Natural neighbors

6.2.3 Bare-Earth surface (Raster Digital Elevation Model)

Bare-earth surface deliverables shall include or conform to the following procedures and specifications:

a) Bare-earth DEM, generated to the limits of the defined project area.
b) All ground-classified points not flagged as withheld shall be used in the creation of the bare-earth DEM.
c) DEM resolution as specified by the user, but not less than ANPS.
d) 32-bit floating-point GeoTIFF raster format.
e) Depressions (sinks), whether natural or man-made, are not to be filled (as in hydro-conditioning). The methodology used for hydro-flattening is at the discretion of the data producer.
f) Bridges shall be removed from the bare-earth surface.
g) Road or other travel ways over culverts remain intact in the surface.

6.2.4 Hydro-flattening:

a) Breakline used for generating hydro-flattened DEM shall be provided separately as a shape file.
b) Hydro-flattening pertains only to the creation of derived DEMs from LiDAR points and breaklines. Hydro-flattening makes no changes to the geometry of the originally computed LiDAR points. Breaklines developed for use in hydro-flattening may also be used to support classification of the point data.

c) Bare-earth LiDAR points (serving as mass points) that are in close proximity to any breakline shall be classified as Ignored Ground (class 20) and shall be excluded from the DEM generation process when the breaklines are included. This process prevents unnatural surface artifacts from being created between LiDAR points and breakline vertices. The proximity threshold for reclassification as Ignored Ground is at the discretion of the data producer, but in general shall not exceed twice the ANPS.

d) Hydro-flattening shall be conducted for natural and man-made water bodies, and water courses. The requirements for hydro-flattening are as follows:
   i. Non-tidal water bodies which have a surface area greater than a specified value as per Table 7 shall be flattened. The minimum features for which breaklines shall be collected and delivered are given in Table 7.
   ii. Water courses greater than a specified nominal width shall be flattened.
   iii. Flat and level water surface bank-to-bank with a gradient downhill water surface, following the immediately surrounding terrain.
   iv. The entire water surface edge shall be at or immediately below the surrounding terrain.

Table 7: Breakline Collection Guidelines for Hydro-Flattening

S. No.	Feature	Rules for capturing Vector data		Remarks
		Minimum Values (m^2)	Minimum values in urban area	
1	Ponds/Lakes	8000 m^2 of Area	1000 m^2 of Area	
2	River/ Stream	30 m in width	10 m in width	
3	Islands	4000 m^2 of area	1000 m^2 of Area	

6.2.5 Forest canopy related models

a) The following kinds of canopy related models can be computed (refer to the “Glossary” section for the definition of these models)
   a) Canopy cover model (CCM)
   b) Canopy surface model (CSM)
   c) Canopy height model (CHM)

b) The grid sizes of the canopy related models shall be specified before the computation. As a general guideline, the grid cell size shall not be less than the ANPS of the LiDAR data.

c) The one of the following interpolation techniques or user-specified technique can be used for interpolation to compute the raster values.
   a) k-Nearest Neighbor
   b) Natural neighbor

6.3 Orthophotos

a) Exterior orientation (EO) parameters derived from GNSS/IMU, and ground control information shall be used in the process of orthorectification.

b) The digital elevation data required for orthorectification shall be produced from the LiDAR data. Also, Digital elevation model (DEM) derived from LiDAR data shall be of sufficient quality and accuracy for orthorectification purposes.

c) The rectification process used for production of orthophotos shall be specified. As a general guideline it is recommended that cubic convolution be used to ensure high accuracy and photograph quality. Other methods such as bilinear or nearest neighbor may also be used depending on the specific requirements of the project.

d) The process of rectification shall involve a solution of the appropriate photogrammetric equations for each pixel in the output photograph. It is not preferable to solve photogrammetric equations at anchor points only and then warp the content of the original photograph between the tie points. Therefore, along with the tie points, the other intermediate points shall also be involved to solve photogrammetric equations. The use of additional tie points beyond the anchor points can help to improve the accuracy of the orthorectification process.

e) The orthophotos shall be seamlessly edge-matched. To ensure consistency, the photographs shall be radiometrically and geometrically corrected to enable adjacent files to be displayed seamlessly.

f) Minimization of photograph distortions and smearing shall be targeted. The presence of warped and misaligned above ground transportation features is not acceptable. However, misalignment of such features shall be within the tolerance defined by the positional accuracy requirement for the LiDAR data set.

g) The approach for ortho-rectification shall be clearly described.

7. LiDAR Deliverables

7.1 List of deliverables

The following are the types of data that shall be delivered after a LiDAR survey.

a) Metadata

b) Ancillary data

c) Laser scanning data

d) Derived data

e) Photographic data, if required by the client

7.2 Metadata

The term metadata refers to all the descriptive information about the project. This includes textual reports, graphics, supporting shapefiles, and National Spatial Data Infrastructure (NSDI) compliant metadata files.

7.2.1 Textual reports

The following textual reports shall be delivered:

a) All data regarding the specifications of the sensors shall be provided (see Section 2.2.2). Documents regarding OEM calibration information certification and preventive maintenance schedule shall be provided.

b) The flight planning and layout specifications will have to be provided in a format recommended in **Error! Reference source not found.** and **Error! Reference source not fo und.**.

c) Report of the calibration survey and the documentation on points of calibration.

d) Reports on the planimetric, vertical and relative accuracies to be provided. (Ensure consistency with other accuracy measures)

e) Reports on the validation of nominal pulse spacing (NPS) and ANPD.

f) Reports on the accuracy assessment of the bare earth surface.

g) Reports on the classification accuracy assessment for each of the classes.

7.2.2 Graphics

a) Area and GNSS / CORS coverage

A map or a set of maps showing the following layers shall be provided:

i. Locations of the GNSS / CORS stations.

ii. The circular buffer areas of radius 30 kms around the GNSS base or CORS stations.

iii. Areas not covered by the buffer areas.

b) Project extents and tiles

i. The project extent shall be delivered as maps for each of the delivered datasets. The project extent area shall not include TIN artefacts, and raster NODATA areas. A minimum bounding rectangle of the surveyed area is not acceptable.

ii. A map of all the tiles shall be provided.

7.2.3 Supporting vector files

The following supporting georeferenced vector files shall be delivered in the same coordinate system and datum, as the complete dataset.

a) The locations of the GNSS / CORS stations.

b) The circular buffer areas of radius 30kms around the GNSS base or CORS stations.

c) The areas not covered by the buffer areas.

d) The project extent (excluding the TIN artefacts and raster NODATA areas)

e) The tiles

f) Breaklines required to compute DEM, DSM, CHM etc.

Furthermore, these vector files shall be provided in interoperable formats which may be any of the following:

i. ESRI shapefile (SHP)

ii. Keyhole markup language (KML)

iii. Geography markup language (GML)

iv. Geopackage layer (GPKG)

v. Any other interoperable format as agreed upon.

7.2.4 NSDI compliant metadata files

Metadata compliant to Indian NSDI Metadata standard 2.0 shall be supplied for the followings:

a) The overall project: An XML file describing the project boundary, the intent of the project, the types of data collected and the various deliverables.

b) Flightlines for a particular project covering the number of swaths, locations of GNSS/CORS base and control stations, preprocessing, and calibration details.

c) For each of the tiled deliverables:

   i. Classified point data

   ii. Bare-earth DEM

   iii. Breaklines (if used)

   iv. Orthophotos (if asked for in the project)

   v. Other LiDAR derived datasets like CHM, DSM, Intensity photographs, height surfaces etc.

7.3 Data delivery

This section presents the standards for delivering LiDAR data and associated deliverables. Unless otherwise mentioned, all data shall be delivered in square shaped tiles. The sizes of the tiles shall be mentioned by data users. The South-West corner of each tile shall be placed on whole kilometer coordinate value, e.g., 426000mE_7243000mN. The data provider shall supply a tile index in .shp, .gpkg, .kml or any other interoperable file format.

The following datasets shall be delivered

a) Trajectory information

b) Smoothed - best estimate of trajectory (SBET)

c) Point cloud data - unclassified, classified and model keypoints

d) Deliverables as agreed.

7.3.1 Trajectory information

The POS-AV file captured by the Intertial Navigation System (INS), during the aerial survey, shall be delivered.

7.3.2 Smoothed best estimate of trajectory

The SBET file shall be supplied in the industry standard format. The contents of the file shall be also delivered in tab separated text file or a schema-based XML file. The schema for the XML file for the SBET file is presented in Table 8. A modified schema can be agreed between data user and data provider.

Table 8: XML Schema for trajectory information

XML Schema	Value
Time	
Altitude	
Latitude	

Longitude	
Roll	
Pitch	
Platform_Heading	
Wander_Angle	
X_vel	
Y_vel	
Z_vel	
X_acceleration	
Y_acceleration	
Z_acceleration	
X_angular_rate	
Y_angular_rate	
Z_angular_rate	

7.3.3 Point cloud data

a) Unclassified point cloud

All LiDAR point cloud data shall be delivered in fully compliant LAS format proposed by ASPRS. The version of the LAS file shall be provided by the client. If no version is provided the default version is 1.4.

All the LAS files shall contain correct and properly formatted georeference information in their headers. The point data would contain x,y and z coordinates and the intensity (at native radiometric resolution) information mandatorily. Other contents of the point data record format (see ASPRS LAS specifications) shall be mentioned explicitly by data user. A proper justification need to be given and agreed by data user if a few fields of LAS file are missing.

Deliverables with waveform data shall use external auxiliary files with the extension. wdp for the storage of waveform packet data. Readers are requested to refer to LAS Specifications 1.4 (or latest) for additional information.

The file naming convention for the LAS files is given in Table 10: Naming convention for unclassified LAS files.

b) Classified point cloud

Classification of the point cloud shall be conducted on a fully calibrated, adjusted to ground data and shall be classified tile wise.

The classified data shall be provided as LAS files in tiles. The tile size shall be provided by the client. The tiles shall be non-overlapping. The minimum classification scheme as listed in Table 5 shall be specified by data user.

All LAS files shall contain correct and properly formatted georeferenced information in their headers. The point data shall contain x, y and z coordinates and the intensity (at native radiometric resolution) information. Other contents of the point data record format (see ASPRS LAS specifications) shall be mentioned explicitly by data user.

c) Model key points

Model Key points (MKP) are a generalized subset of the classified ground points with the Model key point flag as true and represent the minimum number of points required to determine the shape of the ground.

The subset of the ground points (classification label 2) shall be extracted using one of the industry standard methods in practice. The algorithm followed shall be listed in the data processing reports of the project.

The file naming convention for model keypoints are described in Table 13

These photographs will generally cover the entire extent of the survey and shall use the GeoTIFF format. The file naming convention for these photographs is specified in Table 15.

7.4 Aerial photographs and ortho-photography

7.4.1 Basic aerial photos

Aerial photos as captured shall be supplied. Each photograph shall be accompanied with a file mentioning the following data:

a) Focal length of the camera

b) X, Y, Z (cartesian coordinates) in ECEF coordinate system of exposure station

c) Easting, Northing and Up (UTM/WGS84 or UTM/Everest as mentioned by data user) of exposure station

d) Roll, Pitch and Heading

e) Velocities of the aerial platform in X, Y and Z directions

7.4.2 Orthorectified photographs

Orthorectified photographs shall be supplied in square tiles at the sizes mentioned by the data user. The tiles will be same as for LiDAR deliverables.

Each orthorectified photographs shall have georeferencing information with reference to the projection / mapping coordinate system mentioned by the data user embedded in its header.

The file naming convention for the orthorectified photographs can be found in Table 15.

7.5 File naming conventions

The schema for naming the files to be delivered is presented in this section. Each filename contains multiple components which have been explained in the following paragraphs. Following this convention would enable spatial and attribute searches. Each of the file names contains multiple components, wherein the separation between two components is denoted with an underscore (“_”). This convention shall be followed strictly.

7.5.1 Trajectory files

Trajectory files containing industry standard information regarding position of the aerial platform, roll, pitch and heading and velocities in the different directions are to be provided here. Trajectory files could be the POS files obtained from the INS, SBET files obtained through processing of the POS files, tab separated text files or schema-based XML files (see Table 9).

Table 9: Naming convention for trajectory files

Naming convention for airplane trajectory file: ProjectNameYYYY-TRJ_UTMzz.abc		
ProjectName	IITKanpur	A meaningful description of the total survey area.
YYYY	2009	Year of the survey
UTMzz	_UTM44	UTM Zone
Abc	.xml	File types: .out – Applanix SBET file .pos – POS-AV file .xml – Trajectory in XML .txt – Trajectory in text file
Example file name: IITKanpur2009-TRJ_UTM44.xml		

7.5.2 Point cloud files

The point cloud files can be provided as raw points or the classified point clouds. Clients might also be interested in having a model keypoint file. The naming convention for each of these types of files is provided in the following sections.

a) Raw point cloud files

Raw point cloud files are to be provided swath wise i.e. there shall be one file per swath and one swath per file. The file naming convention for the raw, unclassified point cloud files is given in Table 10.

Table 10: Naming convention for unclassified LAS files

Naming Convention for LiDAR point clouds: ProjectNameYYYY-UNC-DAT-SWT-UTMzz.las		
ProjectName	IITKanpur	A meaningful description of the total survey area
YYYY	2009	Year of survey
DAT	-ELL	ELL: Ellipsoidal, MSL: Orthometric
SWT	-1..n	Swath number (1 file per swath)
Zz	_UTM44	UTM zone number of the dataset
For example: IITKanpur2009-RAW-ELL-001_UTM44.las		

b) Classified point cloud files

Classified point clouds are to be delivered in tiles as specified by the client, in the LAS format. The naming convention of these LAS tiles is presented in Table 11.

Table 11: Naming convention for classified point clouds

Naming Convention for LiDAR point clouds: ProjectNameYYYY-CL-DAT_xxxyyyy_UTMzz_wwww_hhhh.las		
ProjectName	IITKanpur	A meaningful description of the total survey area
YYYY	2009	Year of survey
DAT	-ELL	ELL: Ellipsoidal, MSL: Orthometric

xxxyyyy	_4806558 (480,000mE) (6558,000mN)	Easting and northing value (whole kilometre) of the south-west corner of the tile. A single "_" must be used to separate the remaining file name components
UTMzz	_UTM44	UTM zone of the file
wwww	_0002	Width of the tile in whole kilometers
hhhh	_0002	Height of the tile in whole kilometers
For example: IITKanpur2009-CL-ELL_4806558_UTM44_0002_0002.las		

c) Model key point data and single class point clouds

The data user may demand a subset of the entire dataset where all the points in the subset belong to a particular class. The model keypoint files would contain a subset of the class 2 points for a model of the ground points. The file naming convention for such a subset is presented in Table 12.

Table 12: Naming convention for single class point clouds

Naming Convention for LiDAR single class point clouds: ProjectNameYYYY-CL-CLS-DAT_xxxyyyy_UTMzz_wwww_hhhh.las		
ProjectName	IITKanpur	A meaningful description of the total survey area
YYYY	2009	Year of survey
CL	C2	Classification Level (Levels can be 1, 2, 3 and 4)
CLS	-MKP	BLD: Building; MKP: Model keypoints; GND: Ground; LVE, MVE, HVE: Low, medium or high vegetation
DAT	-ELL	ELL: Ellipsoidal, MSL: Orthometric
xxxyyyy	_4806558 (480,000mE) (6558,000mN)	Easting and northing value (whole kilometre) of the south-west corner of the tile. A single "_" must be used to separate the remaining file name components
UTMzz	_UTM44	UTM zone of the file
xwww	_0002	Width of the tile in whole kilometers
hhhh	_0002	Height of the tile in whole kilometers
For example: IITKanpur2009-C2-MKP-AHD_4806558_UTM44_0002_0002.las		

d) LiDAR intensity and other derived photographs

Table 13: Naming convention for LiDAR intensity and other derived photographs.

Naming Convention for LiDAR intensity and other derived photographs ProjectNameYYYY-TYP-GSD-xxxyyyy_UTMzz_wwww_hhhh.tif		
ProjectName	IITKanpur	A meaningful description of the total survey area
YYYY	2009	Year of survey
TYP	INT	INT: Intensity photographs; RGB/RGBI: RGB photographs ; DEM / DSM / CHM / CCM: LiDAR elevation data derived photographs; ORT: Orthophoto
GSD	-002	Ground sampling distance in meters
xxxyyyy	_4806558 (480,000mE) (6558,000mN)	Easting and northing value (whole kilometers) of the south- west corner of the tile. A single "_" must be used to separate the remaining file name components
UTMzz	_UTM44	UTM zone of the file
wwww	_0050	Width of the tile in whole kilometers

hhhh	_0020	Height of the tile in whole kilometers
For example: IITKanpur2009-INT-002_4806558_UTM44_0050_0020.tif		

e) Other datasets

Table 14: Naming convention for other types of files

Naming convention for other datasets (breaklines, project boundary, flight lines etc): ProjectNameYYYY-TYP_UTMzz.abc		
ProjectName	IITKanpur	A meaningful description of the total survey area.
YYYY	2009	Year of the survey
TYP	-BRK	Breakline – BRK; BDR – Project boundary; FGT – Swath bounds; TIL – Tile bounds; CNT – Contour
UTMzz	_UTM44	UTM Zone
abc	.shp	File types: .gml – Geography markup language .kml – Keyhole markup language .gpkg – Geopackage .xml – XML
Example file name: IITKanpur2009-BRK_UTM44.shp		

7.5.3 Aerial photographs

Table 15: Naming convention for aerial photographs

Naming Convention for aerial photographs ProjectNameYYYY-TYP-FLT_FRM.tif		
ProjectName	IITKanpur	A meaningful description of the total survey area
YYYY	2009	Year of survey
TYP	RGB	PAN: Panchromatic; RGB /RGBI: photographs; THM: Thermal; HYP: Hyperspectral; NIR: Near infra-red
FLT	-002	Flight line number
FRM	_006	Frame number
For example: IITKanpur2009-RGB-002_006.tif		

ANNEX A

(*Clause* 2)

LIST OF REFFERED INDIAN STANDARDS

Sl No.	*IS No.*	*Title*

ANNEX B

(*Clause* 2)

LIST OF REFFERED INTERNATIONAL STANDARDS

Sl No.	*International Standards/ Publications.*	*Title*