Fundamentals of DEM Data Acquisition using the LiDAR Survey Method

Presented by the JICA Project Team
At the Institute of Surveys and Mapping – Diyatalawa
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Main Topics of Presentation

1. What is LiDAR Survey
2. Principles of LiDAR Survey
3. LiDAR Survey and Data Processing
4. Advantages and Disadvantages of LiDAR Survey and Usefulness of Data
5. Important Considerations in the LiDAR Survey
6. Data Utilization
7. LiDAR Equipment (Sample)
1. What is LiDAR Survey

- *Pinpoint Laser: Total Station and others*

Specific locations of the target
2. Principle of LiDAR Survey

- The calculation principle of a location/elevation

![Diagram](image)
1. What is LiDAR Survey

- **Ground Survey – Mobile Scanner Type** - It is called “Ground Scanner”; it uses a 3D scanner.
  - A scanner is fixed on a tripod, and the device rotates to scan an area.
  - It could also be mounted on a vehicle. (Stop and Go)

As the scanner rotates, the target area is scanned.
1. What is LiDAR Survey

- **Vehicle Mount Type**
  - It is also called: Mobile Laser or Mobile Mapping System (MMS)
  - Moving survey vehicle and vehicle-mounted laser survey are other names.
  - 2D Scanner is mounted like the airborne type
  - The scanner can scan various directions from the vehicle.
  - The scanner can be mounted on a ship or a car of the railways.

As the vehicle moves forward, all sides of the road can be scanned.
1. What is LiDAR Survey

- **Airborne LiDAR Survey**

The ground is scanned as the aircraft moves forward.
Sample: Urban Data Acquisition
Sample LiDAR Data – Power Station and Port
Sample: Shaded Relief with Contour and Planimetry Overlay
Sample: Orthophoto with Contour and Planimetry Overlay
1. What is LiDAR Survey

- A technology to measure elevation of landform and planimetric features
  - An airborne-LiDAR-survey system is mounted in an aircraft.
  - A GNSS fixed station is installed on the ground.
- The technology will partially replace photogrammetry or field survey.
- Speedy and high quality 3D data acquisition is possible.
2. Principles of LiDAR Survey

- **Airborne LiDAR Survey System Components**
  - **Airborne LiDAR Survey System**
    - GNSS + IMU + Laser Scanner ( + Digital Camera)
  - **GNSS Fixed Station**
    - GNSS Receiving Ground Control Point (Known Coordinates)
  - **Aircraft (Platform)**
    - Fixed-wing aircraft or rotorcraft (rotary wing aircraft)
2. Principles of LiDAR Survey

- **GNSS**
  - The device records the locations of laser emission.

- **IMU**
  - It calculates the direction of laser.
  - The location determined by GNSS is complemented with time.

- **Laser Scanner**
  - It measures the distance and direction from the sensor to the target, i.e. its position relative to the sensor

- **The key condition is that all the devices (system components) function properly.**
  - The coordinates of the GNSS fixed station and the geoid model are also required to obtain the outputs.
3. LiDAR Survey and Data Processing

- **Work Flow**

  - Survey Planning
  - Installation of GNSS *Base* Stations
  - Airborne LiDAR Measurement
  - Measurement of Grnd *Check* Pts
  - Raw Point Cloud
  - Unclassified Point Cloud
  - Ground Data
  - DEM Data
  - Contour Data, Thematic Maps

- **LiDAR Survey**
- **Survey Data for Adjustment**
- **Processing, Analysis**

- **Ortho Photo Image Data**
- Polygon data preparation for *water* bodies
3. LiDAR Survey and Data Processing

- Operation Plan
  - Confirmation of survey areas (operation range)
  - Confirmation of Survey Specifications
  - Selection of Equipment that satisfy the Specifications
  - Preparation of the Survey Flight Plan
3. LiDAR Survey and Data Processing

- Installation of GNSS **Base** Stations
  - Prior to the airborne survey, the base stations need to be installed, and must be occupied for GNSS observations simultaneously with the airborne survey.
  - For accurate analysis, data need to be received and recorded every one second.
  - Currently, the acronym GNSS is used rather than GPS
    - GPS: Global Positioning System
    - GNSS: Global Navigation Satellite System
3. LiDAR Survey and Data Processing

- Measurement of Ground Check Points
  The installation for verification of height data

\[(X_0, Y_0, Z_0)\]
3. LiDAR Survey and Data Processing

- **Verification of Elevation**

  - **On-site survey**
    - $(X_0, Y_0, Z_0)$

  - **Airborne Laser Survey**
    - $(X_1, Y_1, Z_1)$
    - $(X_8, Y_8, Z_8)$

  - Averaged value: $(Z_1, ..., Z_8) = Z_a$

  - Compare and Confirm

  - Ground Check Point
3. LiDAR Survey and Data Processing

Survey Data Acquisition

- The following data are acquired simultaneously
  - GNSS observation data at the GNSS base station
  - GNSS observation and IMU data in the aircraft
  - Laser scan data

- Important considerations for flight planning to acquire accurate data
  - Proper flight parameters
  - GNSS stations locations
  - Proper functioning of system components
  - Climate and weather conditions
3. LiDAR Survey and Data Processing

- **Raw Point Cloud Processing**

  **GNSS baseline analysis:**

  Calculation the position of the aircraft every second

  **GNSS / IMU Integration analysis**

  Correction and interpolation of the position of the aircraft
  Adding the aircraft orientation data to the position data

  200~400Hz
3. LiDAR Survey and Data Processing

- **Raw** Point Cloud Processing

\[
\begin{align*}
(t_1) & : \text{time} \\
(X,Y,Z) & : \text{location of the equipment} \\
(\omega,\varphi,\kappa) & : \text{position of the equipment} \\
(L,\theta) & : \text{scan angle} \\
(x,y,z) & : \text{location of the point group}
\end{align*}
\]
3. LiDAR Survey and Data Processing

- Unclassified Point Cloud Processing

Since the LiDAR survey depend on the GNSS technology it measures the ellipsoid heights. For calculating the MSL, a geoid model is required:

$$\text{MSL} = \text{Ellipsoid height} - \text{Geoid height}$$
3. LiDAR Survey and Data Processing

- Unclassified Point Cloud Processing
  - General Processing Procedure

Confirmation of Height Discrepancies b/w flight lines

Flight line data

Laser scan data

Point clouds measured by every flight line
3. LiDAR Survey and Data Processing

- **Unclassified** Point Cloud Data Processing:

  Offset the elevation values across the plane (for example, 11 cm is added to the z value):

  - Elevation discrepancy 1 (-15 cm)
  - Elevation discrepancy 2 (-7 cm)

  : The results of the Ground Check Point survey for adjustment

  Offsetting the elevation values across the plane (for example, 11 cm is added to the z value)
3. LiDAR Survey and Data Processing

- Ground Data Processing

Section of Point Group (Mountain Slope)

- Non-ground data (vegetation and others)
- Ground (Ground data)
3. LiDAR Survey and Data Processing

Ground Data Processing

- No field work is conducted in ground surface data extraction
- Topography is interpreted from point clouds and ortho-photo images

![Unclassified Point Cloud](image1)

![Ground Data Point Cloud](image2)

- (Gray Points): Non Ground Data
- (Brown Points): Ground Data
3. LiDAR Survey and Data Processing

- **DEM Data processing**
  
  - Also called mesh data
    
    - The amount of the ground data that are random point groups become large; therefore, the grid data are created for easier handling with a computer by interpolating the elevation data.
  
  - Methods of Interpolation (included in the specifications)
    
    - TIN, Max. and Min.
  
  - DTM, DEM, and DSM mean grid data
    
    - DTM : Digital Terrain Model
    - DEM : Digital Elevation Model
    - DSM : Digital Surface Model
3. LiDAR Survey and Data Processing

- **DEM** Data Preparation

  - Ground Data (2D Display)
  - TIN Model Generation
  - Setting the grid

Schematic Presentation of TIN Interpolation
3. LiDAR Survey and Data Processing

- **Contour (Topographic) Data Processing**

  - **Grid Data** (Bird’s Eye View)

  - **TIN Model Generation** (Bird’s Eye View)

  - **Contour Line Data** (Bird’s Eye View)

  Schematic presentation of contour line data generation
3. LiDAR Survey and Data Processing

- **Thematic Map Generation**
  - Shade Relief Map
  - Elevation classification map (DEM • DSM)
  - Slope classification map
  - TIN Model
  - Tree height/planimetric feature height classification map (DSM — DEM)
3. LiDAR Survey and Data Processing

- **Ortho** Photo Image Data processing
  - Automatically processed
  - The purpose is only for confirming the filtering process.
  - Lower quality than the ones from conventional photogrammetry
  - TIFF/TFW (GeoTIFF) format
3. LiDAR Survey and Data Processing

- Polygon data processing for **water** surface

[Diagram of water surface polygon data]
4. Advantages and Disadvantages of LiDAR Survey and Usefulness of Data

- **Advantages of LiDAR Survey**
  - Faster data acquisition, homogeneity of data
  - Wide area coverage (large area in less time)
  - Capability to survey isolated or inaccessible areas
  - Suitability for situation requiring rapid response
  - One most useful thing is that the method can capture the ground data through openings of vegetation cover (compared to conventional photogrammetric method)
4. Advantages and Disadvantages of LiDAR Survey and Usefulness of Data

- Concept of multi-return
4. Advantages and Disadvantages of LiDAR Survey and Usefulness of Data

- The laser beam going through vegetation is an advantage of the LiDAR survey; however, there are cases when ground surface cannot be measured:
  - The ground is covered with leaves of trees and shrubs without a space for the laser beam to reach to the ground.
  - The measurement density is coarser than the gaps among leaves or trunks of trees and shrubs.
  - Water content of the ground under vegetation is high—muddy ground.
  - The energy level of the laser beam is low.
  - The number of returns to be detected has limitation; it is not a continuous return-detection-recording system.
  - Angles of the laser beam to trees are not appropriate; a single line measurement would not lead to sufficient data acquisition of the ground surface data.
4. Advantages and Disadvantages of LiDAR Survey and Usefulness of Data

- Conventional photogrammetry (Stereo mapping)

- Overlap more than 60%
4. Advantages and Disadvantages of LiDAR Survey and Usefulness of Data

- **Airborne LiDAR Survey**

  ![Diagram of Airborne LiDAR Survey](image)

  - Laser beam from an airplane
  - Direct Survey: no information deterioration
  - 3D Topographic Model

  XYZ,XYZ,XYZ...

  Ground
4. Advantages and Disadvantages of LiDAR Survey and Usefulness of Data

- Conventional Aerial Photogrammetry (Stereo Mapping)*

The tree heights are confirmed, and the ground heights are estimated.

Different from the real situations.

Directly measuring the ground

Contour line interpretation from aerial photographs
4. Advantages and Disadvantages of LiDAR Survey and Usefulness of Data

Conventional photogrammetry

Airborne LiDAR Survey
4. Advantages and Disadvantages of LiDAR Survey and Usefulness of Data

- Laser reflection and the number of returns
  - Single return and multi-return
4. Advantages and Disadvantages of LiDAR Survey and Usefulness of Data

- **Disadvantages**
  - No data over obstructed features or areas
  - Loss or degradation of return signal on water bodies, slope plane with low reflection angle and very dark objects.
  - No color information
5. Important Considerations in LiDAR Survey

- Different features of different laser survey equipment
  - Scan distance, Laser class, Multi-return, Waveform recording method, Horizontal and vertical precision

- Differences in LiDAR Survey Parameters
  - Scan distance, pulse rate, scanning pattern, scanning angle, scan frequency, speed along track, footprint (FOV) or swath width
5. Important Considerations in the LiDAR Survey

- **Equipment Calibration**
  - To acquire high precision data, equipment calibration is important. Small misalignment between equipment is identified and adjusted.
5. Important Considerations in the LiDAR Survey

- Differences in Laser Survey Parameters

- Oscillating type mirror

- Scan angle (About $0\sim \pm 30^\circ$)

- Revolving mirror

- Angle $60^\circ$ ($\pm 30^\circ$)

- Scan distance (height from the ground)

- Distance b/w points (perpendicular to the forward direction)

- Distance b/w points (forward direction)

- Swath width

- Scan frequency

- View from above

- Front View

- Laser emitter

- Footprint
5. Important Considerations in the LiDAR Survey

- Considerations based on survey target and purpose

<table>
<thead>
<tr>
<th>Survey Target</th>
<th>Survey Purpose (Applications)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground</td>
<td>River basin management, slope management, monitoring</td>
</tr>
<tr>
<td>Vegetation (trees)</td>
<td>Tree crown or height research</td>
</tr>
<tr>
<td></td>
<td>Vegetation Research</td>
</tr>
<tr>
<td>Artificial structures</td>
<td>Facility Management (location, segment, shape, size)</td>
</tr>
<tr>
<td>Power transmission line</td>
<td>Power line separation study</td>
</tr>
<tr>
<td></td>
<td>Facility management</td>
</tr>
<tr>
<td>Water bodies, and boundaries and surrounding areas</td>
<td>Shoreline study, fiat study, dam/lake sedimentation study</td>
</tr>
</tbody>
</table>
5. Important Considerations in the LiDAR Survey

- Considerations based on Survey Conditions (Environment)
  - Season
  - Topography of the survey area
  - Survey time (Flight duration)
  - Weather
  - Distances and locations of the GNSS Base Stations
5. Important Considerations in the LiDAR Survey

- **Aircraft operation**
  - Safety first!; Proper condition of an aircraft; proper weather condition

- **Quality of data is dependent on the quality of the flight**
  - Adherence to the flight plan; the number of GNSS satellites/PDOP, and GNSS signal reception

- **The quality of the data can only be known after processing**
  - Omission or insufficient overlap; equipment malfunction which was not recognized during the flight; point group data are present, but they do not satisfy the specifications—density requirement and other requirement.
6. Data Utilization (Example 1)

- Contour data generation
  - From the completed DEM Data, contour can be generated automatically to be used as a basis of a topographic map.
6. Data Utilization (Example 2)

- **Longitudinal and Cross-Section Diagrams**
  - longitudinal and cross-section diagrams can be generated at any locations at any intervals.
6. Data Utilization (Example 3)

- Relief Map
  - Micro-topography can be interpreted at locations where they cannot be interpreted in topographic maps. As various relief maps are available, they can be used as the bases of geographic information systems.
6. Data Utilization (Example 4)

- The topographic maps and relief maps can be viewed as 3D models in a birds’ eye view.
6. Data Utilization (Example 5)

- Land slide analysis
  - A land slide analysis can be conducted in areas covered with vegetation.
6. Data Utilization (Example 6)

- Flood simulation
  - Visualization of flood simulation

Water level 40 m

Water level 50 m

Water level 60 m

Water level 70 m
7. Equipment (Aircraft and Sensors)

- **Aircraft**
  
  | Piper PA23 Aztec | 2 motors 250HP |
  | Registration PH-KED | Speed: 90 to 150kts |
  | Wingspan: 11m | Ceiling: 14000ft = 4200m |
  | Length: 9.51m | Range: 850nm |

- **Sensors**
  
  - Lite Mapper 6800i, IGI
  - DigiCam H60, IGI
Thank you for your kind attention