Types of LIDAR Sensor

LiDAR sensors can be broadly classified into 2D LiDAR and 3D LiDAR based on the type of data they capture. The types refer to the dimensionality of the point cloud generated by the LiDAR sensor.

2D LiDAR

1. 2D Mechanical LiDAR

- It uses a rotating or oscillating laser to sweep a single laser beam in a 2D plane.
- Provides a horizontal cross-sectional view of the environment.
- Suitable for applications where a 360-degree horizontal view is sufficient, such as obstacle detection.

2. 2D Solid-State LiDAR

- Utilizes solid-state components like micro-electro-mechanical systems (MEMS) mirrors or other non-mechanical mechanisms.
- Generates a 2D point cloud without the need for moving parts.
- Compact, lightweight, and often more durable than mechanical counterparts.

3. 2D Flash LiDAR

- Captures the entire scene in a single flash of light, providing a snapshot of the environment.
- Suitable for real-time applications and scenarios where a quick overview is sufficient.

3D LIDAR

1. 3D Mechanical LiDAR

- Employs a spinning or oscillating mechanism to capture laser beams in both horizontal and vertical directions.
- Provides a full 360-degree, 3D representation of the environment.
- Ideal for applications requiring detailed 3D mapping, such as autonomous vehicles and robotics.

2. 3D Solid-State LiDAR

- Uses solid-state components to generate 3D point clouds without moving parts.
- Compact, energy-efficient, and often more reliable than mechanical 3D LiDAR systems.
- Suitable for applications demanding a balance between performance and form factor.

3. 3D Flash LiDAR

- Captures a 3D scene in a single flash, providing a rapid and comprehensive snapshot.
- Useful for real-time applications and scenarios where a detailed 3D view is needed quickly.

4. 3D MEMS LiDAR

- Integrates micro-electro-mechanical systems (MEMS) technology to create 3D point clouds.
- Compact, lightweight, and often energy efficient.
- Suitable for applications with size and weight constraints.

5. Hybrid 2D/3D LiDAR

- Combines the advantages of both 2D and 3D LiDAR technologies.
- Can offer a balance between cost, performance, and versatility.

Choosing between 2D and 3D LiDAR depends on the specific requirements of the application. While 2D LiDAR is suitable for scenarios where a 360-degree horizontal view is adequate, 3D LiDAR is essential for applications that demand a comprehensive and detailed representation of the environment in both horizontal and vertical dimensions. 2D Lidar is lower in cost than 3D Lidar, so it completely replaces the 3D Lidar for applications that need moderate or low accuracy.

Comparison between 2D and 3D LiDAR

Table 1. Comparison of 2D and 3D Lidar.

Criteria	2D Lidar	3D Lidar
Number of light beams emitted	It emits only a single beam of light	It is designed to emit several beams of light
Axis of focus	It collects data only in X and Y axes, and beams shot along a horizontal plane.	It collects data in X, Y, and Z axes capturing the vertical plane
Cost	Less expensive compared to 3d Lidar	More expensive than 2D Lidar
Industrial application	Used in activities that require a lot of ranging and detection	It is best suited for mapping and scanning landscapes
Ease of portability	It is smaller in size than 3D Lidar, thus portable	It is more significant than 2D Lidar
Accuracy	Less accurate	More accurate

Some Available LiDAR's in Australia

Model Name	Type	Working	Features	Important Specifications	Cost
N301	**2D**	An optical structure with receiving and transmitting levels side by side. A polar coordinate system is defined, using its centre point as the pole, clockwise as positive, and the outlet direction as zero degrees. The operation involves a laser diode emitting ultrashort laser pulses onto a target object. The diffusely reflected pulses are detected by an optical sensor. Accurate distance measurement to the object is achieved by calculating the time between laser emission and receipt of the returning beam.	TOF principle, with a 360 ° scanning and range of up to 30m. The ranging accuracy is ±3cm, IP67 protection and anti-sunlight glare	Measurement Technique: TOF Wavelength: 905nm Measurement Range: 30m Ranging Accuracy: ±3cm Horizontal: 20Hz:0.36° 10Hz:0.18° Data Content: Distance /Angle Data Points Generated: Max 20,000 points per second. Rotation Speed: 10Hz / 20 Hz FOV – Horizontal: 360° IP: IP67 Communication: Ethernet Voltage: 10V~36VDC Weight: 420g Dimensions: 80*79.1mm	US$691.00 – US$746.00
WxxxC Anti-Collision	**2D**	The LiDAR sensor with internal rotation utilizes the Time of Flight (TOF) distance measurement method, enabling a comprehensive 270-degree two-dimensional scanning capability. The sensor scans the entire 270-degree circle area. By calculating distances in polar coordinates, the sensor determines the presence of obstacles within the set area. Connected to a PC through a USB interface, the LiDAR can configure detection areas (up to 15) by shifting through switching value signals. Additionally, three independent Regions of Interest (ROI) can be freely set within each area.	The farthest working distance reaches xxx*0.1m (eg: W050C, 050*0.1 = 5m), within which the user can set freely according to the environment. IP67 protection and anti-sunlight glare.	Output: Switching value and point cloud rate Scanning Angle: 270° Measurement Range: 5m, 10m Angular Resolution: 1° Monitoring area: Correlation / Independent Rotation Speed: 10Hz Interface: NPN， PNP IP: IP67 Weight: 397g Dimensions (D*H): 80*77.3mm	US$753.00 – US$829.00

M10	**2D**	The M10 LiDAR adopts the TOF principle to be capable of 2-D scanning detection of the surrounding 360 ° environment. M10 uses a wireless power supply and optical communication, measuring frequency for 10khz. The accuracy is to reach ± 3cm with the maximum range from 10 meters. It is mainly used in precise positioning and obstacle avoidance applications.	360° FOV, long measurement range The minimum angular resolution reaches 0.36°, ensuring measurement data is accurate and stable. Configuring an Ethernet interface for high-speed data transmission	Measurement Technique: TOF Wavelength: 905nm Laser Classification: Class 1 Eye-safe/ IEC 60825-1:2007 & 2014 Measurement Range: 5m @ 70% (10m @ 10%) Ranging Accuracy: ±3cm Horizontal: 0.36° Data Content: Distance /Angle Rotation Speed: 10Hz FOV – Horizontal: 360° IP: IP67 Communication Interface: UART (Baud rate 460800) Operation Voltage: 5V Weight: 200g Dimensions (D*H): Φ80*40mm	US$413.00
HS Series	**3D**	HS series high-speed scanning LiDAR sensor has excellent detection accuracy and anti-interference performance, Its measurement range is up to 100 m, and distance accuracy is ±2cm. 200Hz high scan frequency can easily sense high-speed movement objects in time, and accurately capture vehicle contour information. Widely used in over-dimensional vehicle detection, V2X vehicle-road collaboration, high-accuracy surveying and mapping, etc.	The LiDAR sensor has a range of 100m with 10% reflectivity. Operating with a wavelength of 905nm, it employs the Time of Flight (ToF) measurement technique The precision of this sensor is ±2cm, ensuring reliable and detailed distance measurements	**Point Rate:** HS1: 106,000 points/s HS4: 426,000 points/s HS8: 426,000 points/s **FOV (Field of View):** HS1: 120°(H), N/A (V) HS4: 120°(H),-4° ~0° (V) HS8: 120°(H), -6.66° ~2.66° (V) Rotation Rate: 80Hz, 120Hz & 160Hz Channel: 1, 4 & 8 Power Consumption: CH128: 14W CH32: 10W CH16: 9W	
CX16	**3D**	The C16 mechanical high-accuracy lidar scanner adopts the Time-of-Flight method. The 3D laser scanner starts timing (t1) when the laser pulses are sent out. When the laser encounters the target object and the light returns to the	High point density, capable of generating approximately 320,000 3D point cloud coordinates per second.	Channels: 16 Measurement Technique: TOF Wavelength: 905nm Measurement Range: 150m Ranging Accuracy: ±3cm Angle resolution:	US$2,187.00

		sensor unit, the receiving end stops timing (t2). Distance = Speed of Light*(t2 – t1)/2	Wide field of view, with 360°horizontal FOV and 32°vertical FOV. Compact size and lightweight	Horizontal: 5Hz: 0.09º / 10Hz: 0.18º / 20Hz: 0.36º Vertical: 2° Data Points Generated: Max 320,000 points per second. Rotation Speed: 5~20 Hz FOV – Horizontal: 360° FOV – Vertical: -15°~ 15° IP: IP67 Dimensions: 102*78mm Weight: 1000g Communication: Ethernet	

Application of Collected Data

1. 2D LiDAR

The data output from a 2D LIDAR is typically in the form of a point cloud, where each point represents a location in three-dimensional space. The point cloud is a set of (x, y, z) coordinates, where (x, y) denotes the horizontal position in the plane of the LIDAR scan, and z represents the measured distance (range) from the LIDAR sensor. Additionally, some LIDAR sensors may provide additional information, such as intensity values representing the reflectivity of the target.

Extraction of Data

Extracting data from a 2D LIDAR involves capturing and processing the raw output from the sensor. LIDAR data can be obtained through the LIDAR sensor's interface, which may include Ethernet, USB, or other communication protocols. Software development kits (SDKs) or APIs provided by the LIDAR manufacturer are commonly used to interface with the sensor and retrieve the data.

Data Format

Point cloud data can be stored in various formats such as:

- XYZ Format: A simple text-based CSV format where each line represents a point with its (x, y, z) coordinates.
- LAS (LIDAR Data Exchange Format): A binary format commonly used for storing LIDAR data, including point clouds.
- PLY (Polygon File Format): A flexible file format that can store not only point cloud data but also additional attributes such as colour.

Logging Data

Data logging involves recording the acquired LIDAR data for further analysis or archival purposes. The data can be logged in real-time during LIDAR operation or saved after a scanning session. Logging can be done in a continuous stream or segmented based on specific criteria. The choice of logging strategy depends on the application requirements and available storage capacity.

Pre-processing Steps

Before applying machine learning algorithms, pre-processing steps are often necessary to clean and prepare the data. Common pre-processing steps for 2D LIDAR data include:

- Outlier Removal: Eliminating erroneous points or outliers that may result from sensor noise or reflections from non-target objects.
- Ground Filtering: Separating ground points from non-ground points to improve terrain modelling.
- Coordinate Transformation: Converting the point cloud data into a common reference frame if multiple sensors are used.
- Resolution Adjustment: Adjusting the density of the point cloud to meet the requirements of the application.

Applying Machine Learning to 2D LIDAR

- Object Detection: Using algorithms like PointNet or PointRCNN to identify and locate objects in the point cloud.
- Classification: Assigning semantic labels to points, such as labelling points as ground, vegetation, or humans.
- Clustering: Grouping points that belong to the same object or surface.
- Mapping: Creating 2D or 3D maps of the environment based on the LIDAR data.

2. 3D LiDAR

Data Output for 3D LIDAR

The data output from a 3D LIDAR is a point cloud consisting of (x, y, z) coordinates, where (x, y) represents the horizontal position, and z represents the measured distance or height. Each point in the point cloud corresponds to a surface or object within the LIDAR's field of view. Additionally, 3D LIDAR often provides intensity values, which can represent the reflectivity or return intensity of the laser beam.

Extraction of Data

Extracting data from a 3D LIDAR involves capturing and processing the raw point cloud output from the sensor. The data is typically accessed through a software interface or SDK provided by the LIDAR manufacturer, utilizing communication protocols such as Ethernet or USB.

Data Format

Point cloud data from 3D LIDAR sensors can be stored in various formats, including:

- XYZI Format: Like the XYZ format for 2D LIDAR but with an additional intensity value.
- LAS (LIDAR Data Exchange Format): A widely used binary format for LIDAR data that supports 3D point clouds.
- PLY (Polygon File Format): A flexible format that can store 3D point cloud data along with additional attributes.

Logging Data

Logging 3D LIDAR data involves recording the acquired point cloud for further analysis or storage. This process can be done in real-time during LIDAR operation or saved after a scanning session. Logging strategies may involve continuous streaming or segmenting data based on specific criteria, like 2D LIDAR.

Pre-processing Steps

- Outlier Removal: Eliminating points that do not correspond to valid surfaces or objects.
- Ground Filtering: Separating ground points from non-ground points for terrain modelling.
- Voxelization: Grouping points into voxels to reduce data density and facilitate downstream processing.
- Coordinate Transformation: Aligning multiple scans or sensors to a common reference frame if needed.

Differences in Pre-processing from 2D LIDAR

- Voxelization: 3D LIDAR data is volumetric, and voxelization involves dividing the 3D space into small cubes (voxels) to handle the increased complexity of 3D data.
- Advanced Outlier Removal: Due to the additional dimensions, outlier removal algorithms may need to consider spatial relationships between points in all three dimensions.

Applying Machine Learning to 3D LIDAR

- Feature Extraction: Extracting relevant features from the 3D point cloud, which can include geometric features, intensity values, or other attributes.
- Training Data Preparation: Creating labeled datasets for training machine learning models. This involves annotating points or regions of interest in the point cloud.
- Algorithm Selection: Choosing appropriate machine learning algorithms such as PointNet, PointRCNN, or deep learning architectures tailored for 3D data.
- Training and Inference: Training the model on the labelled dataset and applying it to new, unseen 3D LIDAR data for inference.

Differences in Applying Machine Learning from 2D LIDAR:

- Dimensionality: Machine learning models for 3D LIDAR need to handle the additional dimension, requiring modifications or the use of algorithms designed for 3D data.
- Complexity: Due to the richer information in 3D point clouds, machine learning models for 3D LIDAR may be more complex than those for 2D LIDAR.
- Integration with Other Sensors: 3D LIDAR is often part of a sensor fusion system, and machine learning models may need to integrate data from other sensors like cameras or IMUs.

ML Algorithms

1. Gait Analysis

Objective: Analyzing gait patterns and dynamics derived from features such as step length, stride length, and foot pressure distribution.

Approach

a. Data Preprocessing

- Extract LiDAR point clouds containing human shapes.
- Segment and track individual limbs to derive gait-related features.

b. Feature Extraction

- Compute features like step length, stride length, and foot pressure distribution from the segmented point clouds.
- Apply algorithms such as Principal Component Analysis (PCA) to capture essential gait-related information.

Algorithms

- Support Vector Machines (SVM): Train SVM models to classify different gait patterns based on extracted features.
- Random Forest: Utilize Random Forest for gait pattern recognition and feature importance analysis.
- Deep Learning (e.g., CNN): Train a convolutional neural network to automatically learn hierarchical representations from raw point cloud data.

2. Health Assessment

Objective: Assessing the overall health and well-being of users based on extracted features related to posture, balance, and biometric data.

Approach

a. Data Preprocessing

- Extract LiDAR point clouds capturing the entire body and surrounding environment.
- Segment and analyze body posture and balance.

b. Feature Extraction

- Derive features related to body posture, balance, and other biometric data from the point cloud data.
- Use statistical measures and geometric features to quantify health-related metrics.

Algorithms

- Decision Trees or Random Forest: Build models to assess health based on extracted features.
- Regression Models: Predict health scores or indices based on the extracted health-related features.
- Deep Learning (e.g., LSTM): Leverage recurrent neural networks for analyzing temporal aspects of health-related data.

3. Anomaly Detection

Objective: Identifying deviations or irregularities in gait patterns or health metrics that may indicate potential health issues.

Approach

a. Data Preprocessing

- Establish a baseline for normal gait patterns and health metrics from the training data.
- Identify normal ranges for features.

b. Feature Extraction

- Extract relevant features from gait and health-related data.

Algorithms

- Isolation Forests: Detect anomalies by isolating instances in feature space.
- One-Class SVM: Train the model on normal instances to identify anomalies.
- Autoencoders: Use unsupervised learning to learn normal patterns and detect anomalies.

4. User Feedback

Objective: Providing personalized feedback or recommendations to users based on the analysis of gait and health data.

Approach

a. Data Preprocessing

- Continuously collect and update user-specific gait and health data.

b. Feature Extraction

- Extract features relevant to gait and health for individual users.

Algorithms

- Recommender Systems: Utilize collaborative filtering or content-based recommendation approaches to provide personalized feedback.
- Clustering Algorithms (e.g. K-Means): Group users with similar gait and health patterns to tailor feedback.

Key Findings

1. For our gait analysis project, opting for 2D LiDAR is cost-effective and well-suited, considering factors such as affordability, range, and accuracy.
2. All LiDAR sensors available in the market carry an IP67 Rating, mitigating any risk of damage from dust, dirt, or adverse weather conditions.
3. Processing 2D point cloud data is computationally less demanding compared to its 3D counterpart, which requires intricate pre-processing due to its volumetric nature.
4. Mohd Yusuf et al.'s research has showcased a prototype of a 2D LiDAR mapping system, demonstrating its capability to generate 3D point cloud models.
5. The application of machine learning algorithms can be systematically organized based on specific tasks, involving experimentation with recommended algorithms and subsequent performance evaluation using standard metrics.