TITLE PAGE

- **Problem Statement ID – SIH26053**
- **Problem Statement Title- Adaptive Variable Resolution 2.5D Lidar Mapping for Dynamic Environment Perception**
- **Theme- Smart Vehicles**
- **PS Category- Software**
- **Team ID- 143452**
- **Team Name - Gol D.**

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FOVEA-NET: Intelligent Adaptive LiDAR Perception

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Problem Statement

Adaptive Variable Resolution 2.5D Lidar Mapping for Dynamic Environment Perception

Proposed Solution

FOVEA-NET: An AI-driven system that builds a variable-resolution 2.5D elevation map from LiDAR data. It retains crucial height data while minimizing compute costs by dynamically focusing high resolution only on critical risks and the vehicle's predicted path

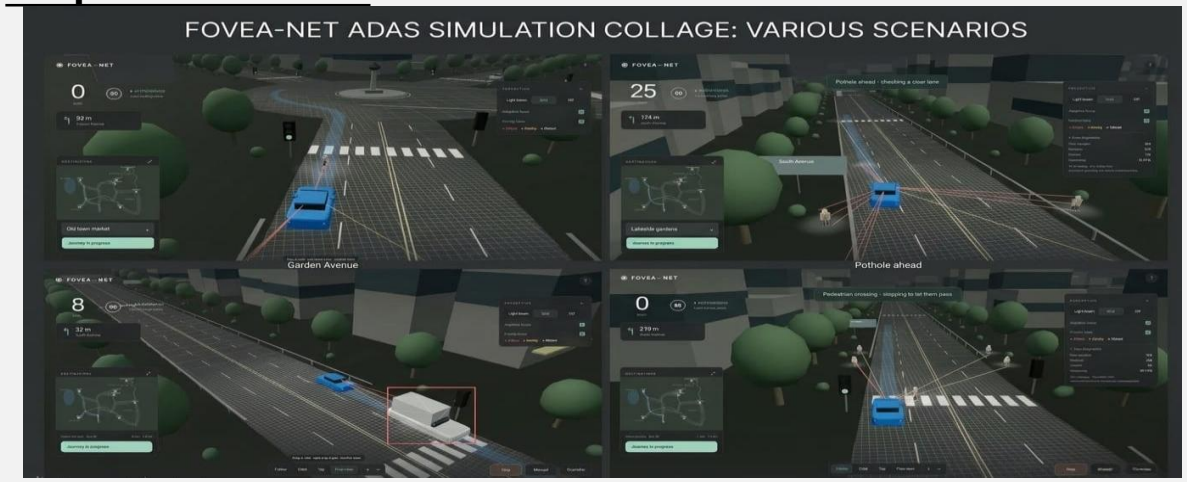
Link : https://youtu.be/WWgDjudSdd4

Innovation and Uniqueness

Perception-Aware Compression: Acts like human foveal vision by dynamically scaling resolution based on actual object risk and the vehicle's predicted path, rather than using fixed distance rings.

2.5D Efficiency: Retains crucial 3D height data while maintaining the computational efficiency of a simple 2D grid.

Proposed Solution



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TECHNICAL APPROACH

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Functions of the System	Technologies Used
LiDAR Point Cloud Acquisition	LiDAR sensor, Open3D, NumPy
LiDAR Point Cloud Pre-processing	Open3D, NumPy, Point Cloud Filtering
Semantic Segmentation	PointNet++ , PyTorch
Terrain & Obstacle Classification	PointNet++, Sparse Convolutional Networks
Risk & Attention Estimation	Vehicle predicted path, object risk, uncertainty analysis
Adaptive Resolution Mapping	Variable-resolution 2.5D Elevation Grid, Morton(Z-order) Coding
Dynamic Object & Hazard Tracking	Temporal Memory, LiDAR-based object tracking
Real-Time Visualization	JavaScript, Three.js, Interactive 2.5D Dashboard
Simulation & Testing	CARLA Simulator, simulated LiDAR
Dataset Training & Evaluation	SemanticKITTI, nuScenes-LiDARseg

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FEASIBILITY AND VIABILITY

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Feasibility:

- **Built with Existing Technology:** Uses LiDAR, PyTorch, Open3D and NumPy with proven point-cloud processing techniques.
- **Ready Data & Simulation:** SemanticKITTI provide labelled data, while CARLA enables realistic LiDAR testing.
- **Prototype Ready:** Pre-trained models and a modular architecture make development feasible within the SIH timeline.

The Challenge | Our Solution:

- **High computation | Adaptive Resolution:** High detail only where the vehicle needs it.
- **LiDAR sparsity | Sensor Fusion:** Camera-LiDAR fusion improves long-range perception.
- **Boundary & data loss | Smart Grid:** Morton-coded sparse grid preserves spatial and height information.
- **AI uncertainty | Safety Layer:** A fixed 10 m safety zone ensures minimum resolution near the vehicle.
- **Model complexity risk | Fallback Pipeline:** RANSAC fits a plane to separate drivable ground from obstacles, and DBSCAN clusters the rest into distinct objects, a fast fallback if the deep learning model isn't ready in time.

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IMPACT AND BENEFITS

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- **Smarter Perception**

Dynamically focuses mapping detail on high-risk, decision-critical areas, improving situational awareness.

- **Computational Efficiency**

Avoids unnecessary high-resolution processing, reducing computation, memory usage, and processing load.

- **Enhanced Safety**

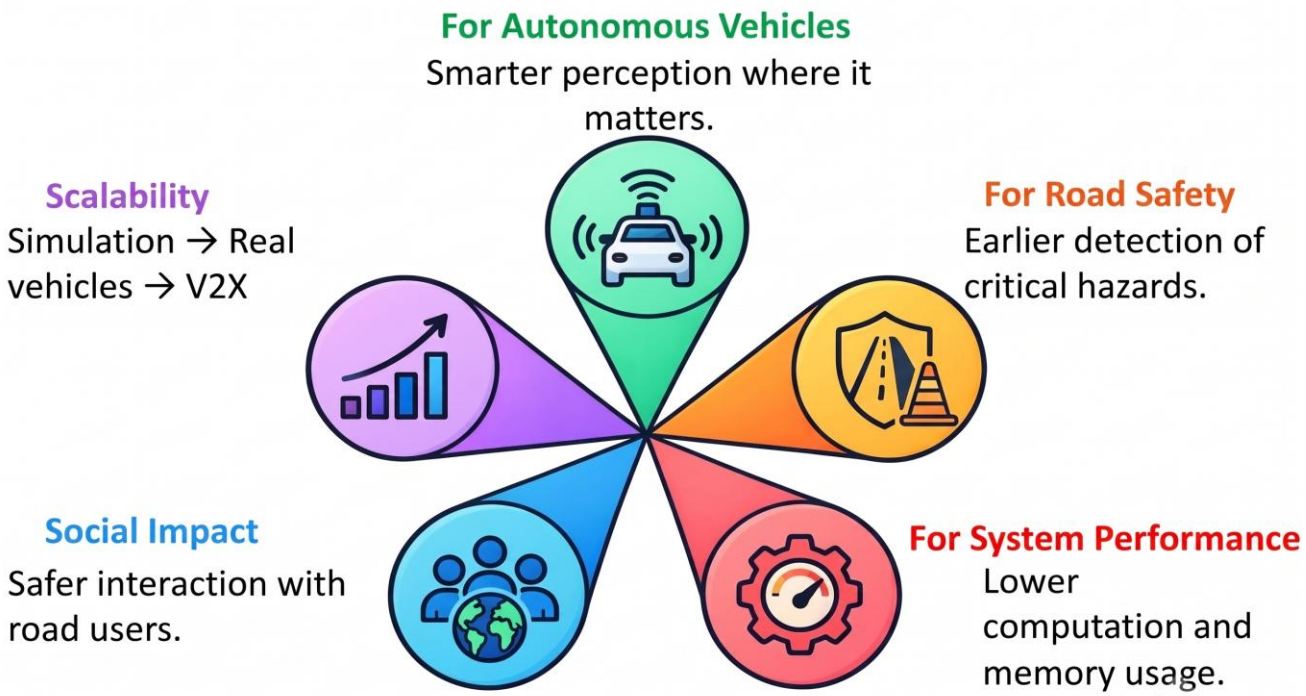
Improves awareness of pedestrians ,cyclists, obstacles, potholes, and terrain changes for safer navigation.

- **Social Impact**

Enables safer and more reliable autonomous mobility for vehicles and road users.

- **Scalable & Future-Ready**

Scales from simulation and datasets to real-world LiDAR, with potential for V2X and fleet integration.



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RESEARCH AND REFERENCES

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Core Research Papers for FOVEA-NET

1. PointNet++: Deep Hierarchical Feature Learning on Point Sets in a Metric Space
Authors: Charles R. Qi, Li Yi, Hao Su, Leonidas J. Guibas
Link: https://arxiv.org/abs/1706.02413

2. Robot-Centric Elevation Mapping with Uncertainty Estimates
Authors: Péter Fankhauser, Marco Hutter, et al.
Link: https://www.research-collection.ethz.ch/handle/20.500.11850/155254

Dataset and Simulation References

3. SemanticKITTI: A Dataset for Semantic Scene Understanding of LiDAR Sequences
Authors: Jens Behley, Martin Garbade, Andres Milioto, Jan Quenzel, Sven Behnke, Cyrill Stachniss, Jurgen Gall
Link: https://arxiv.org/abs/1904.01416

4. nuScenes: A multimodal dataset for autonomous driving
Authors: Holger Caesar, Varun Bankiti, Alex H. Lang, Sourabh Vora, Venice Erin Liong, Qiang Xu, Anush Krishnan, Yu Pan, Giancarlo Baldan, Oscar Beijbom
Link: https://arxiv.org/abs/1903.11027

Phase	Action	Tech Stack
1. Setup & Data	Ingest point cloud data and initialize the simulation environment.	CARLA, SemanticKITTI, Open3D
2. Perception AI	Run semantic segmentation to classify terrain, static obstacles, and dynamic objects.	PyTorch, PointNet++
3. Core Mapping	Construct the variable-resolution 2.5D elevation grid using risk estimation.	NumPy, Morton Coding
4. Visualization	Render the adaptive elevation map and track hazards in real-time.	JavaScript, Three.js

Feature	Traditional 2D Grid	Full 3D Voxel Mapping	FOVEA-NET (Our Solution)
Retains Height Data	❌	✅	✅
Low Compute & Memory Cost	✅	❌	✅
Resolution Scales with Risk	❌	❌	✅
Perception-Aware Compression	❌	❌	✅
Dynamic Hazard Tracking	❌	✅	✅