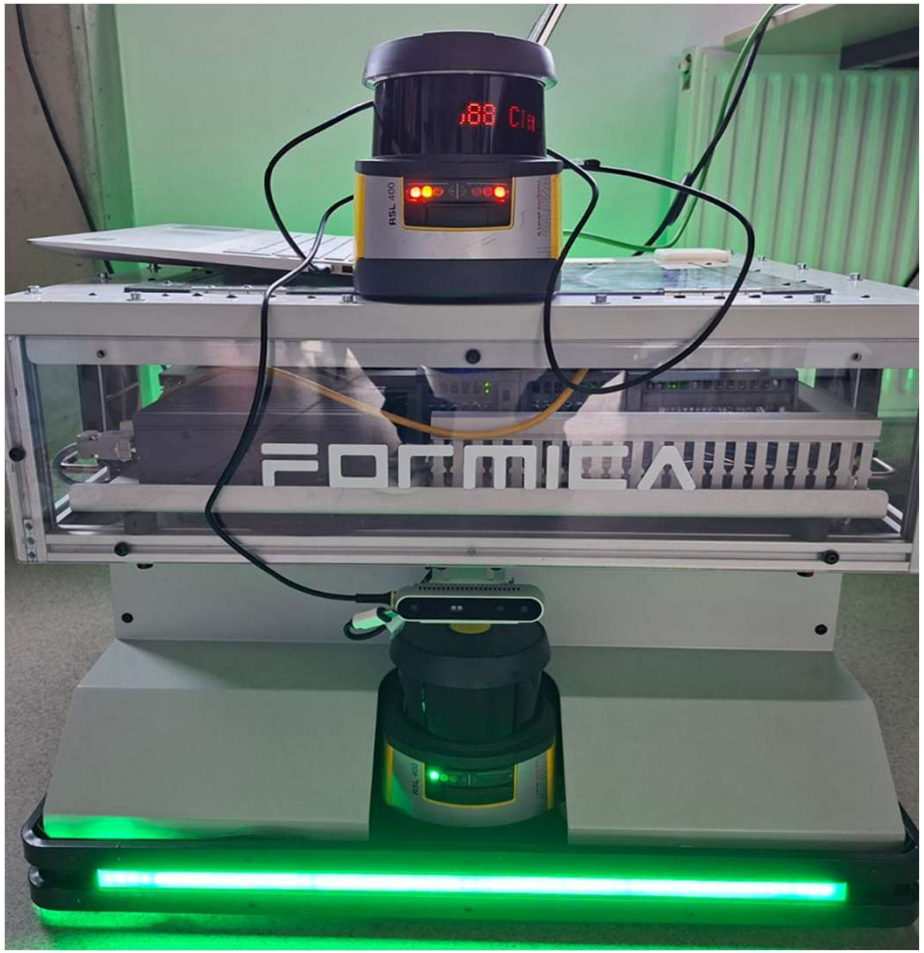
Lightweight Model for Collision Avoidance of AGVs in Crowded Environments

OUTLINES

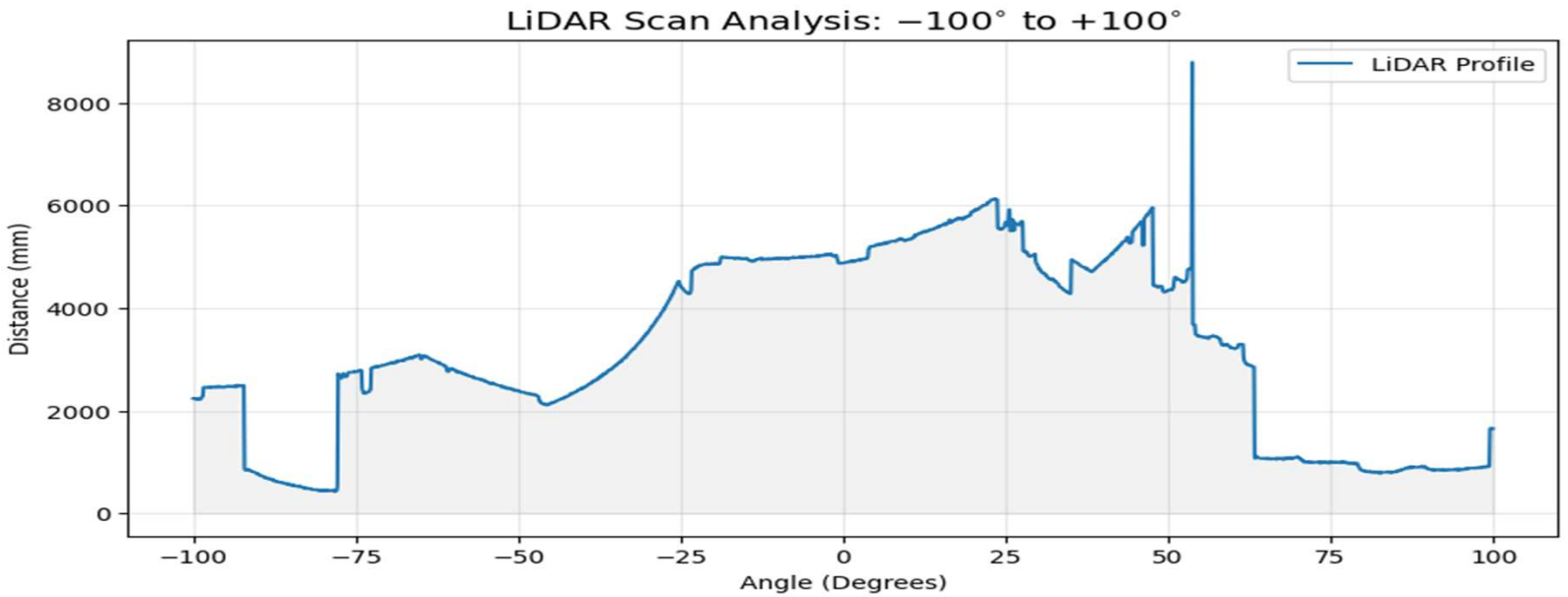
- Data type
- Data preparation and loading
- Model Architecture
- Training and Evaluation
- Risk Assessment

Data type



	Lidar RSL 400
Data type	Numerical
Dimension	2D
Parameters	- Distance - Angle (**-135 to +135**) - Start and stop Index (**0 to 2700**) - Warning field (0 or 1) - Safety field (0 or 1) - Index Interval (40ms) - Scan number (517 scans)

Data Preparation and Loading



- **Data Source:** LiDAR sensor data captured in a CSV format, covering a field of view from -100 to +100
- **Extraction:** Data is parsed using a step-jump of 10 rows to align with the hardware's 400ms scan interval, ensuring temporal consistency.
- **Feature Mapping:** Each sample extracts 2,001 data points representing distances (Index 2008–4008) and their corresponding angular timestamps.
- **Sequence Generation:** Unlike static models, we use a Sliding Window approach. Individual scans are grouped into sequences of 5, allowing the model to perceive movement and velocity.

Data Preparation

- **Normalization:** Raw distance values (0–10,000mm) were scaled between **0 and 1**. This accelerates neural network convergence and prevents high-distance values from dominating the gradients.

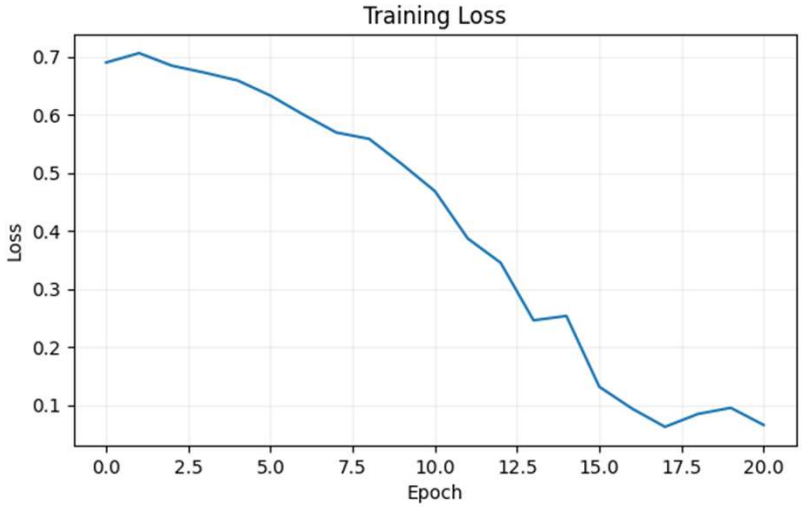
- **Reshaping:** Data was transformed into a 4D tensor (Samples, TimeSteps, Points, Channels) to satisfy the input requirements of a Time-Distributed CNN.
    - **Samples (Dimension 0):** This is the total number of sliding window sequences. We created sequences using a window size of 5. With 52 original scans, we got 48 sequences.
    - **TimeSteps (Dimension 1):** This is 5, our window size. Each sample is a sequence of 5 consecutive scans, allowing the model to see temporal patterns.
    - **Points (Dimension 2):** This is 2,001, the number of distance measurements per scan (representing angles from -100° to +100° from the dataset).
    - **Channels (Dimension 3):** This is 1, as we have a single channel containing distance values.

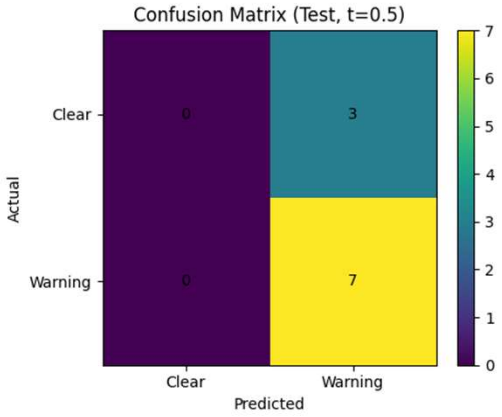
Model Architecture and Training

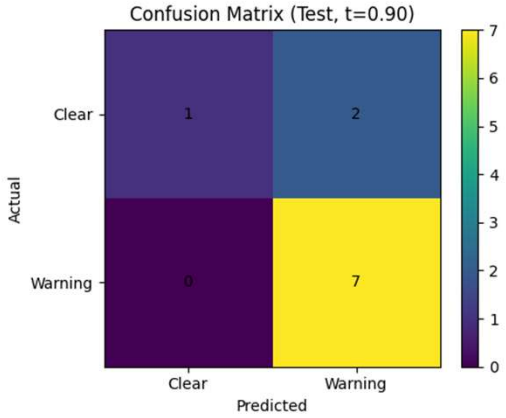
Hybrid Architecture

- **1D CNN:** Act as spatial feature extractors to identify the "shape" of obstacles in individual scans.
- **GRU** (Gated Recurrent Unit): Acts as temporal memory to analyze the change between the 5 sequential scans, identifying if an object is approaching.
- **Optimizer:** The Adam optimizer was used with Binary Cross-Entropy loss, as the goal is a binary classification: Clear Path (0) vs Warning Path (1).
- **Hyperparameters:** The model was trained over 50 epochs with a batch size of 4, optimizing for both speed and accuracy.

Training and Evaluation







- **Leak Reduced Evaluation Setup:** We applied a blocked, time-based train–test split with a purge gap to ensure that temporally adjacent LiDAR windows do not appear in both the training and test sets.
- **Proof of Concept on Current Runs:** The current experiment uses a limited number of real AGV runs and is presented as an initial proof of concept; performance will be re-validated as more real data is collected.
- **Learning Trend:** The training loss decreases steadily, indicating that the CNN–GRU learns meaningful patterns from sequential LiDAR scans.
- **Safety-First Outcome:** Confusion matrix results show no missed Warning states (False Negatives ≈ 0), which is the most critical requirement for safe AGV operation.
- **Practical Threshold Setting:** Threshold tuning (e.g., 0.5 → 0.90) allows controlling false alarms while maintaining safety (FN ≈ 0), supporting practical deployment calibration.

Risk Assessment

Fuzzy inputs

Front Minimum Distance (FMD)

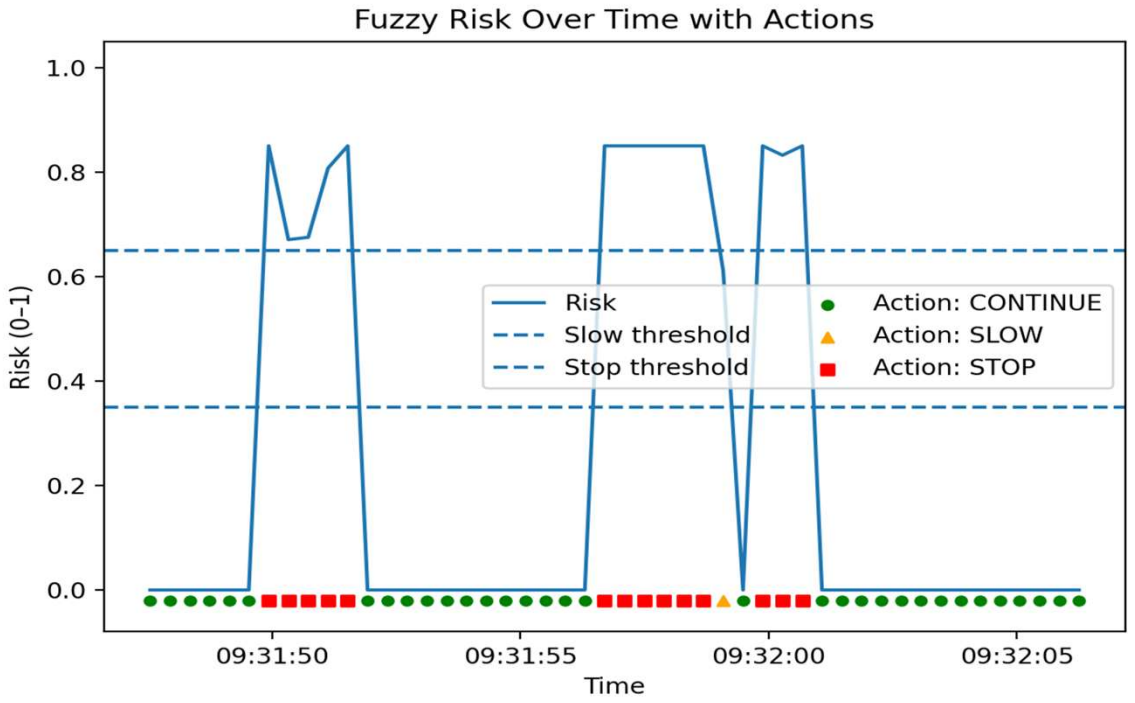
- Extracted from LiDAR geometric features
- Computed as the minimum distance in the front sector (e.g. −20° to +20°)
- Represents immediate geometric safety

Time-to-Collision (TTC)

- Computed from the distance trend over time
- Uses consecutive FMD values
- Represents temporal urgency and future collision risk

Collision Probability

- From CNN-GRU output
- Represents learned likelihood of a collision-prone motion pattern



Risk Level	Action	Control Meaning
< 0.35	Continue	Normal operation
0.35 - 0.65	Slow	Preventive deceleration
> 0.65	Stop	Emergency avoidance