Lane Detection for Autonomous Driving From Multi-Sensor System

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Introduction

Objectives

Our project aims to develop an autonomous solution that can detect and track lanes and roads with high accuracy and reliability using a multi-sensor system. By achieving this goal, we aim to contribute to the advancement of autonomous driving technology and HD map generation, ultimately improving road safety and transportation efficiency.

Main Components

- Image processing for lane detection.
- Road segmentation and labelling.
- Lane detection evaluation.

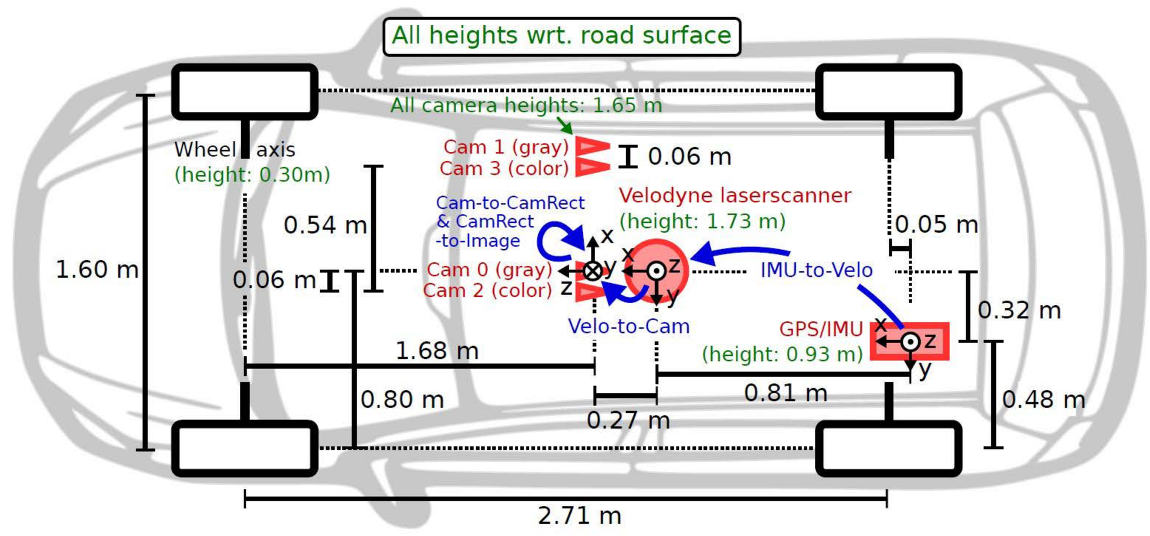
Background

KITTI Dataset

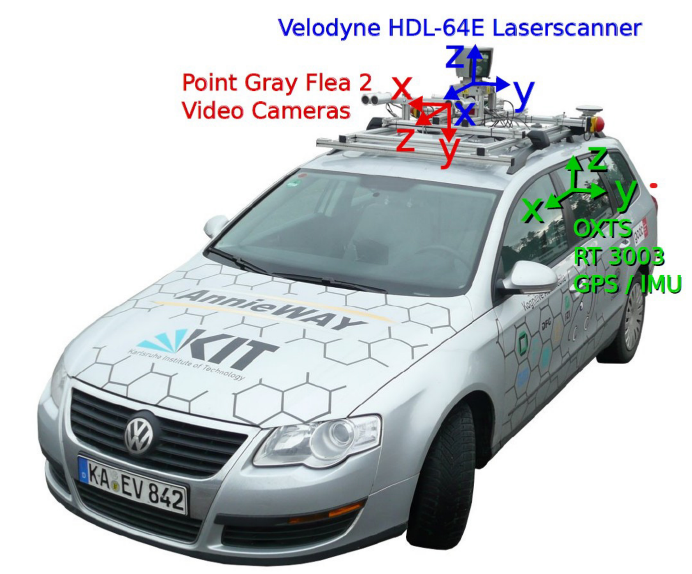
All required data are obtained from KITTI which provides datasets captured by cameras, Velodyne and GPS/IMU sensors mounted on a vehicle.

Sensor Fusion

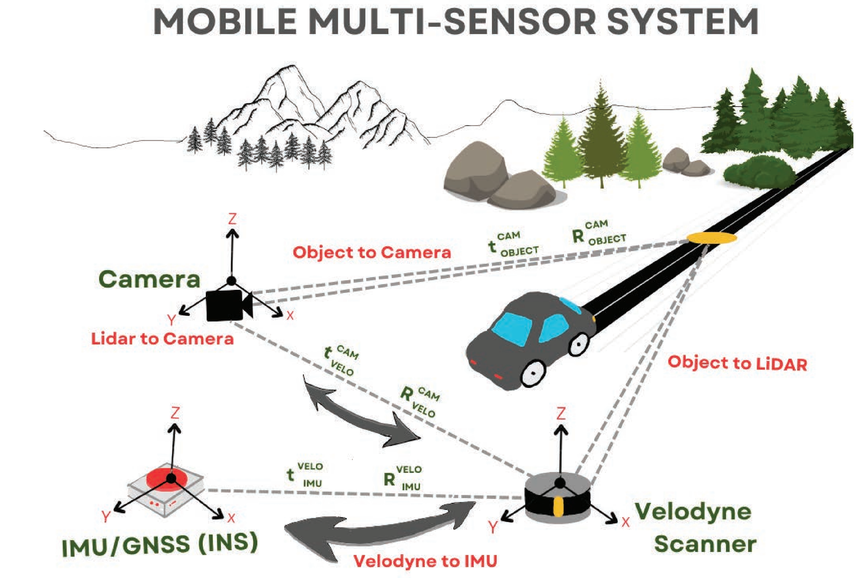
KITTI also provides the calibration dataset required for coordinate transformation from Velodyne to camera and from IMU to Velodyne.



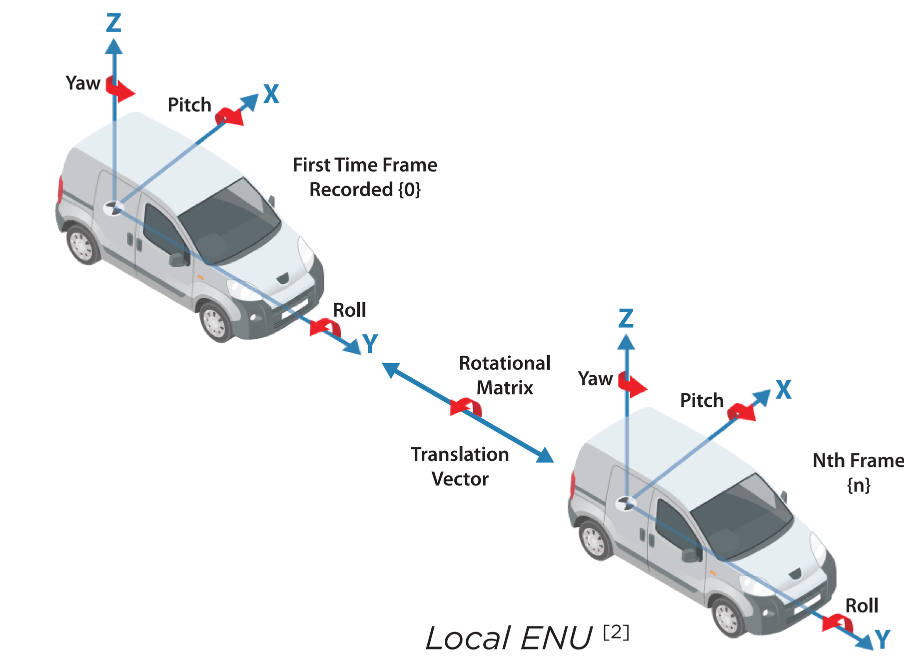
KITTI Sensor Structure [1]



KITTI Vehicle Recording Setup [1]



Sensor Fusion



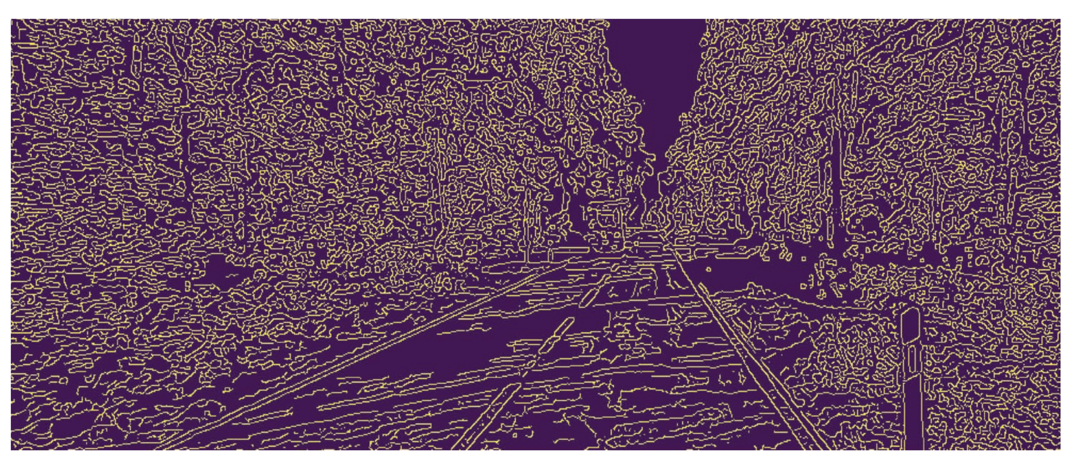
Local ENU [2]

Methodology

In this project, several computer vision and sensor fusion algorithms were employed to achieve a favorable outcome. The progression of the project and the operation of our tool are depicted in the accompanying images, which illustrates the output generated at each stage.

Lane Detection

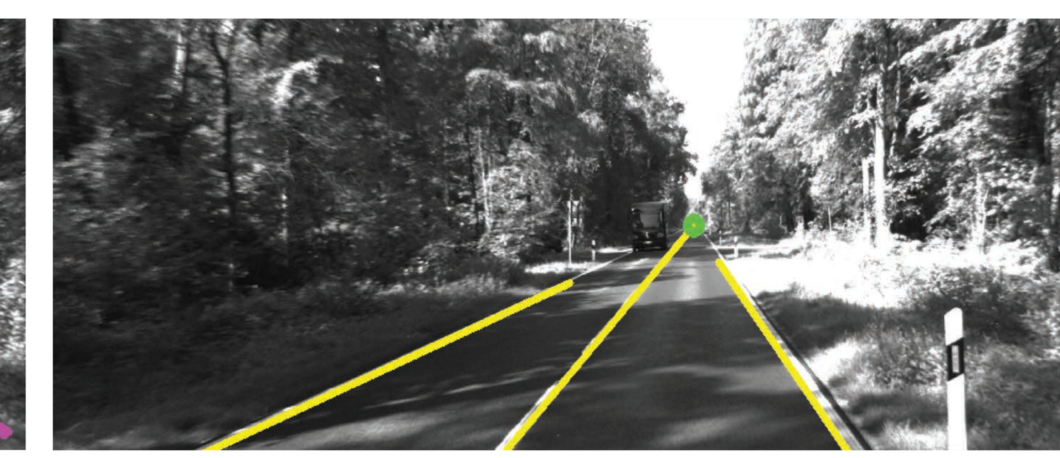
In lane detection, the images were obtained from the KITTI dataset and underwent preprocessing that involved converting them to grayscale, detecting edges and lines, and reducing noise. To detect lane markings, the Canny Detection and Hough Transformation algorithms were employed. Additionally, a new algorithm was developed to eliminate potential false lane markings by leveraging the properties of the lane such as its length, angles, and location in the image. A region of interest (ROI) was then defined based on the outlines of the road and a vanishing point, which allowed for accurate road segmentation and labelling. Finally, the inner lane markings were detected in the ROI.



Canny Detection was utilized to identify all edges in the image by detecting significant changes in pixel intensity.

Hough Transform algorithm was implemented to identify potential lines in the image.

Image noise was eliminated by exploiting the properties of the lane.



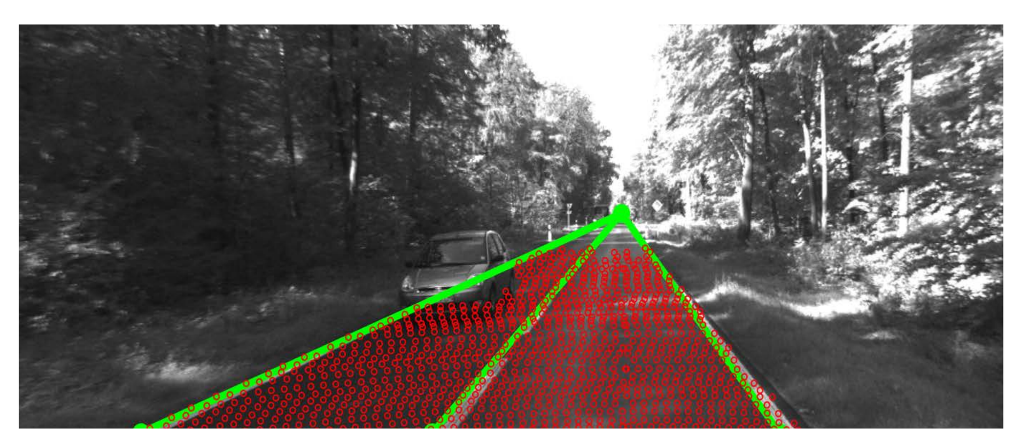
The two outer lanes detected were intersected to identify a vanishing point and the position of the inner lane was determined.

Road/Lane Data Labelling & Integration

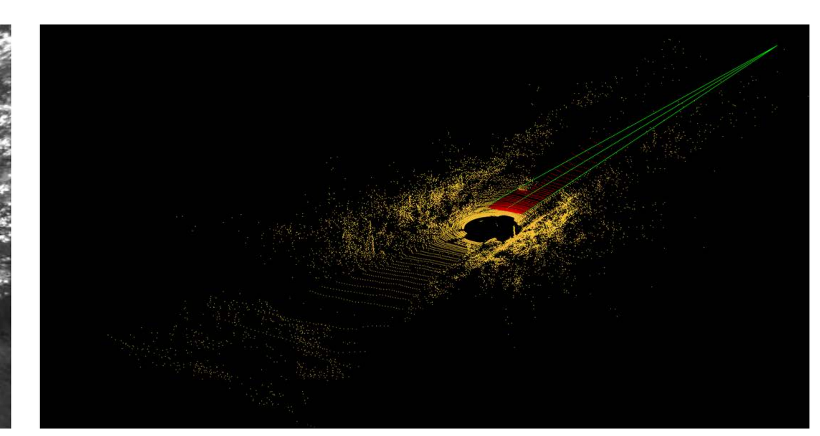
LiDAR point cloud is a valuable resource for obtaining 3D information, particularly in the context of detecting lanes and roads for autonomous driving and HD map generation. One approach to detecting possible road features is to use the RANSAC algorithm. However, this approach yields inaccurate results, and improvements are required. Our proposed solution is to integrate computer vision for lane detection and the identified 3D road points from RANSAC to enhance our results' accuracy. At each time stamp, developed algorithms are used to evaluate LiDAR points, effectively detecting and labelling lane and road features. Additionally, calibrated multi-sensor system facilitates data transformation and fusion, enabling efficient feature extraction and data labelling on the point cloud.

Road/Lane Data Labelling

Our system labels road points based on detected lanes at every available time frame, ensuring accurate and up-to-date information on the road environment.



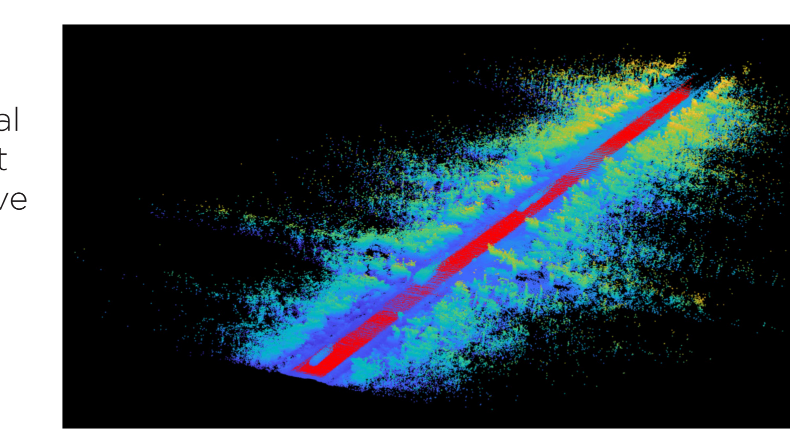
Road Segmented 2D Image



Road Segmented 3D Image

ENU Integration

To integrate all point clouds in the collected time frame, we use a local ENU frame, which enables efficient data processing and comprehensive feature extraction. This approach allows us to create a seamless and accurate 3D representation of the road environment.



Road Segmented 3D Image ENU

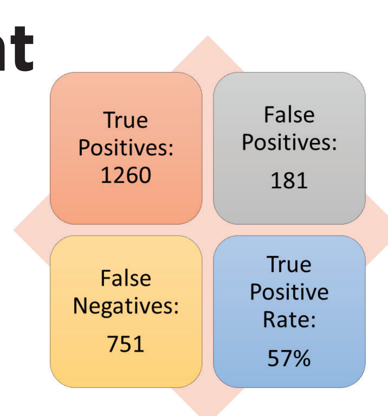
Data Analysis Accuracy Assessment

Lane Detection (Quantitative)

The accuracy of the lane detection was automated with the use of the MATLAB Ground Truth Labeler App. Here the real or true lanes can be identified through visual inspection, as seen in image: *Ground Truth Label Session*. Then a line is fitted between the two-lane points and compared against the detected lanes. First the slopes are checked to see if they are within 0.5 units threshold, and then the y-intercept is checked to see if it's between a 100-pixel threshold.

Then each true lane is assigned a status based on the following criteria:

- True Positive: The lane was successfully detected.
- False Positive: A lane was detected where there was none.
- False Negative: The lane failed to be detected.



Lane Detection Accuracy Metrics

Ground Truth Label Session

Road/Lane Data Labelling (Qualitative)

To ensure the practical application of our system, we enabled ground truth frame as a possible reference point for data analysis and validation. This ensures that our system delivers relative accurate and reliable results in real-world scenarios, making it a valuable tool for road safety and navigation.

Lane Detection Accuracy Metrics

Drive	Description	True Positive	False Positive	False Negatives	True Positive Rate	Accuracy
2011_09_26_drive_0002	Drive through urban with train tracks to the left and bike lane	139	32	65	59%	81%
2011_09_26_drive_0027	Drive through straight road with minimal cars	456	11	108	79%	98%
2011_09_26_drive_0015	Countryside drive with train tracks to the left and incoming cars	464	66	203	63%	88%
2011_09_26_drive_0028	Drive through curvy road with many incoming cars	201	72	375	31%	74%

Final Deliverables

Program Package

Autonomous program package developed in C++, MATLAB & Python for a calibrated multi-sensor system used in mobile mapping to detect and label lane/road data.

Github Repository

https://github.com/ZzZifanZ/LaneDetection/tree/Lane-Detection

Results can be customized based on desired applications, examples:

- All point clouds and detected features integrated in the collected time frame on a local ENU frame.
- Projected on a ground truth frame based on a satellite map.
- Detected lanes based on computer vision per frame.

Lane Detection Result With Map

References

[1] A. Geiger, P. Lenz, C. Stiller, and R. Urtasun, "Vision meets robotics: The KITTI dataset", The International Journal of Robotics Research, vol. 32, no. 11, pp. 1231–1237, Sep. 2013, doi: 10.1177/0278364913491297.

[2] Photo adapted from "Coordinate Systems in Automated Driving Toolbox", MathWorks, Vehicle Coordinate System, https://www.mathworks.com/help/driving/ug/coordinate-system s.html

Road Segmented Map