## PAPER 1

**PAPER:** A lane detection method based on 3D-LiDAR

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**PUBLICATION:** Automotive Research & Testing Center (ARTC), Changhua, Taiwan (R.O.C)

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Lane detection is crucial information for driving autonomy. To build a safe and robust lane detection system, 3D LiDAR based lane detection, capable of detecting all direction and working in all lighting condition, is an ideal sensor redundancy in addition to camera-based lane detection. The LiDAR can detect the intensity of road surface points, so the lane mark will appear as high intensity point segment in each scan layer. The regrouping of clusters into lanes is a challenging task due to the discontinuity of road lane, the variety of road direction and configuration, and the presence of other road marks beside lane marks. A method has been proposed to incorporate road edge detection to predict local road geometry model which assists mark-segment regrouping into lane and unrelated mark filtering. Experiments show the method is efficient, and can run in a real-time environment.

**Results:** In this study, the method is used by LiDAR sensor rather than camera which common on lane detection. According to the feature of road geometry, the slope, continuity and smoothness of the point clouds are considered to be analyzed to define the definite road surface and boundary. Since the road boundary is definite, the relationship between lane and boundary is easy to construct. The direction of lane is almost identical as the road boundary in ideal environment. Thus the road surface searching by this method could define as the whole lane, and the central lane line could divide the lane into left part and right part.

## PAPER 2

**PAPER:** A Path Planning Algorithm for Lane-Following-Based Autonomous Mobile Robot Navigation

**AUTHOR:** Yazan Aljeroudi, Mark Paulik, Mohan Krishnan, Chaomin Luo

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In this paper we address the problem of autonomous robot navigation in a "roadway" type environment, where the robot has to drive forward on a defined path that could be impeded by the presence of obstacles. The task of the path planner is to ensure that the robot follows the path without turning back, as can happen in switchbacks, and/or leaving the course, as can happen in dashed or single lane line situations. The first behavior determines a goal using a center of gravity (CoG) computation from the results of image processing techniques designed to extract lane. The second behavior is based on developing a sense of the current “general direction” of the contours of the course. This is gauged based on the immediate path history of the robot. An adaptive-weight-based fusion of the two behaviors is used to generate the best overall direction.

**Results:** The multi-behavior-based path planning model proposed in this work draws inspiration from the type of inputs that human drivers use in steering a vehicle. One behavior is the need to maintain continuity with respect to the immediate path history, while another is to analyze the scene in front, to extract visual cues for directing the vehicle towards its ultimate destination. The results of this model works very well in a simulation environment thus validating its underlying premise. However, it works only moderately well on an actual course due to noise artifacts introduced by the basic vision module employed. This experience suggests a potential line of enquiry in the future.

## PAPER 3

**PAPER:** Lane Detection Algorithm Using LRF for Autonomous Navigation of Mobile Robot

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**PUBLICATION:** Test & Evaluation Division, Korea

**E-ISSN:** Appl. Sci. 2021, 11, 6229. https://doi.org/10.3390/app11136229

This paper proposes a lane detection algorithm using a laser range finder (LRF) for the autonomous navigation of a mobile robot. The lane detection is a fundamental requirement for an automobile system that utilizes the external environment information of automobiles. Representative methods of lane recognition are vision-based and LRF-based systems. In the case of a vision-based system, the recognition of the environment of a three-dimensional space becomes excellent only in good conditions for capturing images. In this paper, a three-dimensional lane detection algorithm using LRF that is very robust against illumination is proposed. For the three-dimensional lane detection, the laser reflection difference between the asphalt and the lane according to color and distance has been utilized with the extraction of feature points.

**Results:** This paper proposed a real time lane detection algorithm using LRF (Laser Range Finder) for autonomous navigation of a mobile robot. There are some unexpected barriers, such as bad illumination, occlusions, and vibrations that the vision cannot be used for satisfying the fundamental requirement, and conventional lane detection has mainly been carried out by using vision-based methods, but such methods have a serious drawback of showing substantially diminished performance in driving environments where reliable vision-based information is not obtained, such as under conditions of dense fog. Therefore, in this study, we built a laser-scanned 3D road map and discerned and recognized lanes by using a feature point extraction algorithm using LRF calibration and amplification errors depending on the materials and colors of the asphalt and the lanes. The test results confirmed that the use of the proposed method could ensure safe driving under unfavorable road conditions such as fog, which could contribute to the R&D on autonomous driving technologies.

## PAPER 4

**PAPER:** Real-Time Road Lane Detection in Urban Areas Using LiDAR Data

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**PUBLICATION:** Department of Computer Science and Engineering, korea

**E-ISSN**: Electronics 2018, 7, 276; doi:10.3390/electronics7110276

The generation of digital maps with lane-level resolution is rapidly becoming a necessity, as semi- or fully-autonomous driving vehicles are now commercially available. In this paper, we present a practical real-time working prototype for road lane detection using LiDAR data, which can be further extended to automatic lane-level map generation. Given a 3D point cloud scanned by a 3D LiDAR sensor, we categorized the points of the drivable region and distinguished the points of the road signs on the ground. Then, we developed an expectation-maximization method to detect parallel lines and update the 3D line parameters in real time, as the probe vehicle equipped with the LiDAR sensor moved forward. The detected and recorded line parameters were integrated to build a lane-level digital map with the help of a GPS/INS sensor.

**Results:** In this paper, the overall system consisted of two subsystems, including point categorization and road line detection. Given the 3D LiDAR point cloud, we categorized the points of the drivable region and distinguished the points of the road signs on the ground. Then, we presented an expectation-maximization process to detect and update the 3D line parameters in real time. The detected road lines were represented as densely- and uniformly-distributed 3D points on the lines with the help of a GPS/INS sensor and integrated to generate a lane-level digital map.

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| A lane detection method based on 3D-LiDAR | Yu-Fang Wang and Yi-Shueh Tsai | Automotive Research & Testing Center (ARTC), Changhua, Taiwan (R.O.C) |  | Lane detection, 3D-LiDAR, Road geometry |
| A Path Planning Algorithm for Lane-Following-Based Autonomous Mobile Robot Navigation | Yazan Aljeroudi, Mark Paulik, Mohan Krishnan, Chaomin Luo | Intelligent Robots and Computer Vision XXVII: Algorithms and Techniques | SPIE Vol. 7539, 75390M © 2010 SPIE-IS&T · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.838926 | Camera, LADAR, Lane |
| Lane Detection Algorithm Using LRF for Autonomous Navigation of Mobile Robot | Jong-Ho Han and Hyun-Woo Kim | Test & Evaluation Division, Korea | Appl. Sci. 2021, 11, 6229. https://doi.org/10.3390/app11136229 | Lane tracking, 3D map, laser range finder; curvature |
| Real-Time Road Lane Detection in Urban Areas Using LiDAR Data | Jiyoung Jung, ID and Sung-Ho Bae | Department of Computer Science and Engineering, Korea | Electronics 2018, 7, 276; doi:10.3390/electronics7110276 | road lane detection; map generation; driving assistance; autonomous driving |