Road Attribute Tracking System

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***Abstract*—The most commonly used navigation systems often use vehicle density and distance to select the shortest route. But road conditions also play a vital role in determining the same. There are instances where we reach a place and find out that the road is either small or in a very poor condition and hence the information obtained was false. This project mainly focuses on the collection of data or information on a specified travel route based on which a person can choose or identify the best and most comfortable route among the several possible routes. The basic idea is to gather data like the road's width, the number of humps, potholes, etc. For the same, we use a suitable high-resolution fused camera and LiDAR sensor interfaced to a Jetson nano board and mount the same on a vehicle preferably a car. The data hence collected can either be stored using an onboard storage device like a hard disk or can directly be fed to the server or cloud using a WiFi module as required. The sensors will be mounted on the vehicle so that we can scan the entire span of the road in a single run and collect video and depth perspective data simultaneously for further analysis and computations. Since the sensors are scanning the road, they are to be kept facing the road i.e., downwards, this somewhat resembles the way the headlight of the vehicle lights the road. The camera here gives us an overall view of the number of obstacles that are present on the road. LiDAR gives the depth data which gives a more accurate identification of the pothole. The collected data are computed or processed using the YOLO algorithm. The programming part is done using Python. The collected data is suitably filtered and compiled into a database that can be used for future reference.**

***Index Terms*—Yolo, Camera, Lidar, Jetson nano**

I. Introduction

Autonomous navigation is rapidly becoming the future of the automobile industry, where the goal is to achieve fast and safe commutation. Sensor fusion is a critical technique used to gather information from the surrounding environment regardless of weather and other environmental conditions. ROS (Robot Operating System) is an industry-standard framework utilized for robotics applications and development. Additionally, with recent advancements in AI, it is now possible to implement models on small-scale embedded devices, making it easier to integrate them into real-world applications. Vehicle detection is crucial for advanced driver assistance systems (ADAS), and both LiDAR and cameras are commonly used. LiDAR provides an excellent range of information but is limited in object identification. On the other hand, the camera provides better recognition but is limited in high-resolution range information. Hence, fusing data from LiDAR and cameras in real time is a crucial process in many applications, such as autonomous driving, industrial automation, and robotics. The fusion of data from these two sensors enables the depth of objects as well as the detection of objects at short and long distances.

II. Objectives

The primary objective of this project is to develop a sensor array using LiDAR and a mono camera that can accurately detect and track potholes on the road surface. This system will be integrated into an overall architecture based on the ROS framework. The system will provide real-time information on the width of the road, the location and depth of potholes, and any humps or other obstacles. This information will be passed on to the user, and will also be used to improve the efficiency of path-planning algorithms in autonomous navigation applications. By accurately detecting and tracking potholes on the road, this system will help to improve road safety and reduce vehicle damage. It will also allow users to make informed decisions about the best route to take based on road conditions. The integration of LiDAR and mono camera data will provide a more complete picture of the road environment, allowing for more accurate detection and tracking of potholes and other obstacles. Overall, the goal of this project is to improve the efficiency and safety of autonomous navigation systems through the integration of LiDAR and mono-camera data.

III. Block Diagram

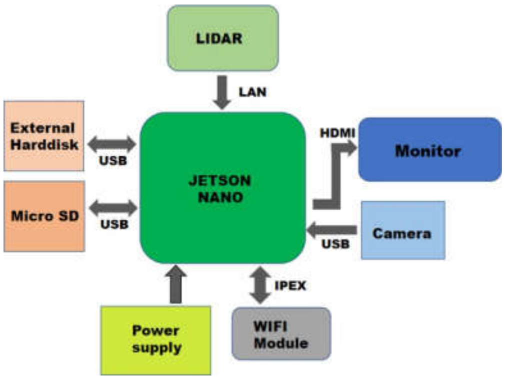

Fig. 1. Block Diagram

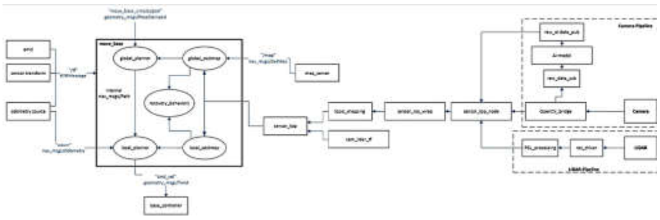

Fig. 2. Internal Architecture

IV. Flow Of Data

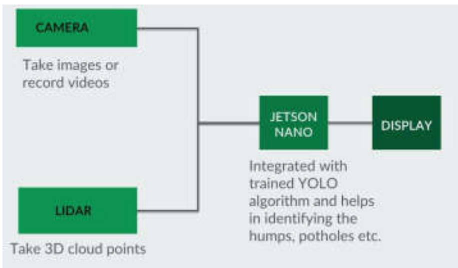

Fig. 3. Flow Diagram

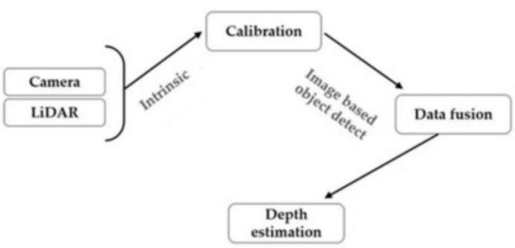

Fig. 4. Flow of Data

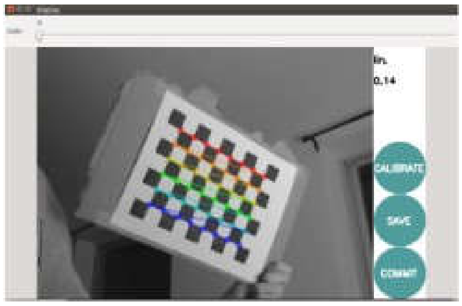

Fig. 5. Checker Board Calibration Node

A. Camera Calibration

Camera calibration is an important process that involves estimating intrinsic and extrinsic parameters of a camera to obtain accurate and reliable images. The process of camera calibration was done using the camera calibration package in ROS for calibrating a mono camera. The camera calibration package in ROS provides a tool for calibrating a mono camera's intrinsic and extrinsic characteristics. To estimate the camera's parameters, the software uses a chessboard pattern as a calibration object. The procedure involves capturing multiple images of the calibration object from different viewpoints and then using these images to estimate the camera parameters.

B. Collecting training data sets

We have downloaded and bounded 3000 images. Almost 500 images and videos were taken by the team members of R.A.T.S., We have labeled the dataset using labelling software. The classes are potholes (We can also train it to detect humps and other common objects).

C. Training of YOLO

We trained the YOLO algorithm using Google Colab. The labeled datasets are uploaded in google collab. After training, we will get a Yolo weight file and a cfg file. We will download these files to the Jetson Nano and perform onboard detection. YOLO (You Only Look Once) is a method/way to do object detection. We are going to use the OpenCV DNN module with a custom-trained YOLO model for detecting Potholes (We can also train it to detect humps and other common objects).

D. Testing

We tested the trained model using the experimental setup. This setup has sharp edges and a rapid depth, providing a reliable testing environment. Additionally, real-time data such as potholes was used to test the trained model. The number of potholes detected was also calculated.

E. LiDAR data Customization

Proper calibration of the LiDAR sensor is crucial to the accuracy and reliability of the pothole detection system. The process involves analyzing the data from the LiDAR. The average depth of the road surface is determined by collecting and analyzing the scan data from the LiDAR sensor by the

LiDAR calibration node. This is achieved by eliminating points that do not belong on the road surface, and then using the points that remain, building a 3D point cloud of the road surface. The average depth value is then calculated by the node by taking the mean of the z-coordinates of all the points in the point cloud. To accommodate for variations in road surface height, a safety margin is added to the average depth value to obtain the threshold value. Due to variables in road surfaces, including road curvature and vehicle weight, this margin is required. The pothole identification algorithm uses the generated threshold value to locate regions where the road surface depth is below the threshold, indicating the presence of a pothole.

F. Camera-LIDAR alignment

Transformation matrix calibration is a critical step in achieving accurate alignment between a camera and LiDAR sensor. The goal is to determine the relative position and orientation of the two sensors in 3D space. For TF calibration we used a checkerboard pattern with known dimensions as a calibration target. The target was placed within the field of view of both sensors, and images and point clouds were captured simultaneously. These data are then used to estimate the transformation matrix.

After the TF calibration was complete, the LiDAR sensor was mounted on top of the camera sensor, considering the maximum overlap of the field of view. This setup ensures that the edges are sharp and the depth is rapid, resulting in more accurate results.

Overall, TF calibration is a crucial step in achieving accurate alignment between a camera and LiDAR sensor, and it enables the fusion of data from both sensors for improved accuracy and reliability.

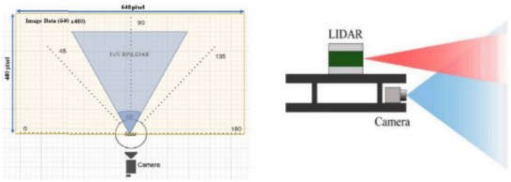

Fig. 6. Camera-LiDAR Arrangement

G. Sensor Fusion

Sensor fusion is a technique that combines data from multiple sensors to improve the accuracy and reliability of pothole detection. Here we are performing the fusion of data from LiDAR and Camera sensors. Accurate distance measurements are provided by LiDAR, and high-resolution images are taken by the camera for object detection. By fusing the data from both sensors, the system can identify potholes more accurately, with fewer false detections.

The LiDAR sensor is used to measure the distance to the road surface and creates a point cloud, while the camera captures images of the road surface. YOLO algorithm is then used to detect potholes in the images. The point cloud from the LiDAR is then overlaid onto the images, and the data from both sensors are combined to identify the potholes accurately.

H. Circuit Assembly

The fused sensor setup (Camera + LiDAR) was suitably configured and connected to the Jetson Nano using a USB port (Camera) and RJ45 (LiDAR). Power is supplied to the Jetson Nano using a 5V 4A adapter, connected using a barrel jack. The SD card flashed with a compatible version of Jetpack is inserted.

I. Output Data

We performed ROS bag to CSV file conversion in the jupyter notebook platform using Python programming. ROS bag has many topics from which we extracted only the required topics like nodes for camera input, LiDAR input and the combined output node which is the transformation matrix. By doing this we can eliminate large amounts of irrelevant and redundant data that were initially present in the ROS bag by extracting only the required topics and converting them into a CSV file. This will facilitate faster data transfer by reducing data size and eliminating the wastage of data.

V. Related Works

Byeong-Ho Kang et al. developed Pothole detection system using 2D LiDAR and camera, to improve the pothole detection accuracy, the combination of heterogeneous sensor system is used. By using 2D LiDAR, the distance and angle information of road are obtained. The pothole detection algorithm includes noise reduction pre-processing, clustering, line segment extraction, and gradient of pothole data function. Next, image-based pothole detection method is used to improve the accuracy of pothole detection and to obtain pothole shape. Image-based algorithm includes noise filtering, brightness control, binarization, addictive noise filtering, edge extraction, and object extraction and pothole detection. To show the pothole detection performance, experiments of pothole detection system using 2D LiDAR and camera are performed.

Schoenberg et al. fused the LIDAR with the camera image on a pixel-level, and for each LIDAR point there is a pixel in the image corresponding to it. Therefore, each point is added a pixel of color intensity information. This method only uses of the intensity information and suffered from non-overlapping region problems. An improved approach presented by Cho et al., who extracted the data features of each sensor respectively, and combines them to classify and track the moving objects. The work by Schlosser et al. performed a pedestrian detection task by combining the 3D-LIDAR data and the RGB image on different levels of the convolution nets.

Anoop et al. developed a novel road attribute detection system for autonomous vehicles using sensor fusion. To enhance the reliability and accuracy of road attribute detection, they combined data from multiple heterogeneous sensors, including LiDAR, camera, and GPS. The system first processes LiDAR data to obtain high-precision 3D information about the road surface and surrounding structures. The LiDAR-based algorithm involves ground segmentation, feature extraction, and classification of road attributes like lane boundaries, curbs, and obstacles. Simultaneously, camera-based detection methods are used for lane marking recognition, traffic sign identification, and texture analysis of the road. The camera processing pipeline includes image enhancement, deep learning-based feature extraction, and semantic segmentation. GPS data is integrated to provide global positioning and route-level context. Sensor fusion is performed using a probabilistic framework to combine outputs from different sensors, thereby improving the robustness of the system under varying environmental conditions. To validate the performance, a series of experiments were conducted in diverse real-world driving scenarios.

VI. Experiment and Evaluation

A. *Object Detection using YOLO algorithm*

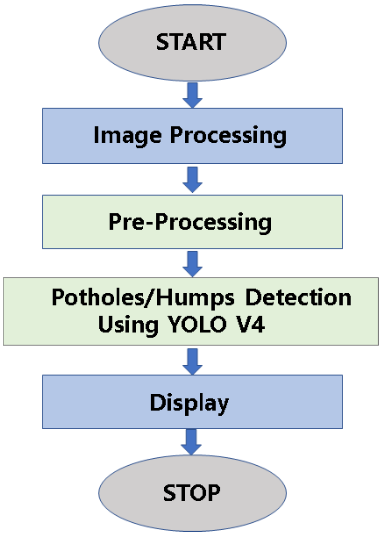

Fig. 7. Algorithm

The camera sensor is suitably mounted on the outside of the vehicle preferably a car from which the inputs will be taken. Different travel paths of intend are selected. Each of the routes in the travel paths are individually scanned. The data acquired are stored both onboard and simultaneously on backup storage. The Jetson Nano helps to interface all the sensors together. These data are then analyzed and processed based on the YOLO algorithm. YOLO detects and recognizes various objects in a picture. The algorithm requires only a single forward propagation. YOLO is used to predict various class probabilities and bounding boxes.

B. *Detection setup*

To create an artificial pothole for testing purposes, a cardboard box is used with a hole in it connected to a pipe. This setup allows for sharp edges and a rapid depth, providing a reliable testing environment. The box serves as a reference surface for the sensors, which will be placed in various positions to measure the depth and scanning range of the pothole.

Fig. 8. Test Setup

The sensors used in the setup will depend on the specific pothole detection system being developed. However, commonly used sensors include LiDAR and cameras, which are mounted on a vehicle or placed on the road surface. These sensors capture data from the pothole and surrounding area, which is processed by algorithms to detect the pothole and its characteristics such as depth, size, and location. By using this detection setup, researchers and developers can test and fine-tune their pothole detection algorithms in a controlled environment before deploying them in the real world. This helps to ensure the accuracy and reliability of the system and reduces the risk of false detections and other errors.

C. *Experimental Results*

Fig. 9. Detection using LiDAR sensor

Simulated Results:

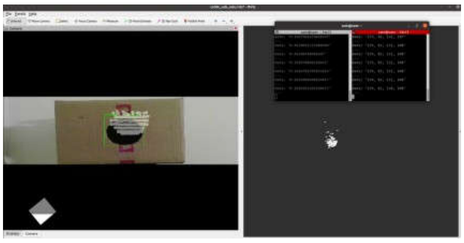

Fig. 10. Test 1

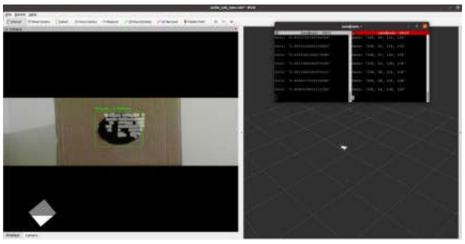

Fig. 11. Test 2

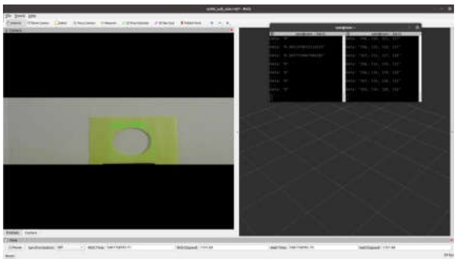

Fig. 12. Test 3

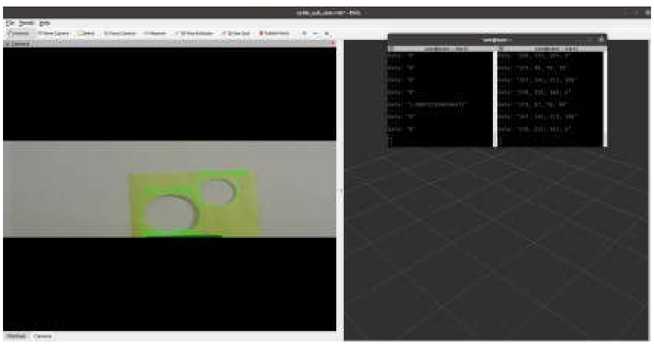

Fig. 13. Test 4

Camera Pipeline test setup Simulated Results

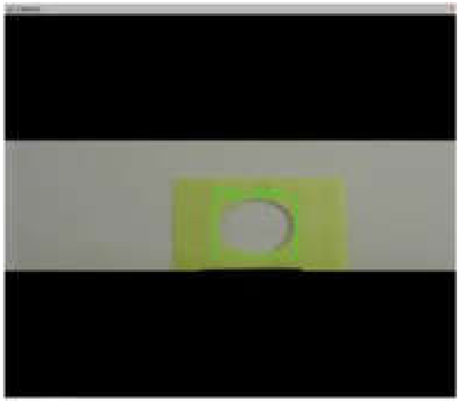

Fig. 14. Test Case 1

Fig. 15. Test Case 2

Fig. 16. Test Case 3

VII. Result

A. Detection

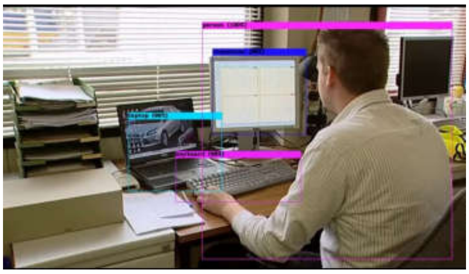

Fig. 17. Sample Detection

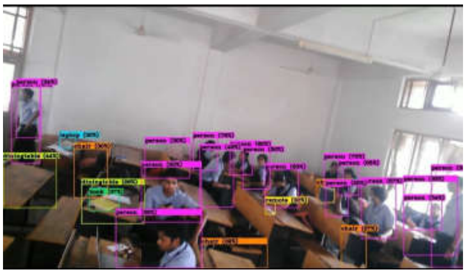

Fig. 18. Classroom Detection

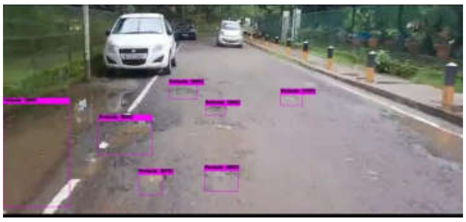

Fig. 19. Pothole Detection

B. Comparison of Deep Leaning Models with Common Dataset

Models	F1 Score	Precision	Recall	mAP	Accuracy
Yolo	0.96	0.93	0.98	98.19	97
SSD	0.88	0.90	2.87	90.56	88
Mask R-CNN	0.90	0.86	0.94	93.72	73
NanoDet	0.76	0.80	1.75	91	90

C. Comparison of Deep Learning Models with Custom Dataset

Models	F1 Score	Precision	Recall	mAP	Accuracy
Yolo	0.85	0.82	0.87	87.08	86
SSD	0.66	0.72	1.76	60.45	77
Mask R-CNN	0.62	0.75	0.73	72.61	62
NanoDet	0.75	0.74	0.74	79	74

D. Comparison Of YOLO and NanoDet with Live input

Objects	Manual	YOLO	NnaoDet
Potholes	107	125	95
Humps	9	15	4
FPS	–	3	5

Fig. 20. Detection Result 1

E. Result of Vertically Placed Sensors

Type	Pothole Detected	Number of Potholes Detected	Depth of Pothole	Fusion Detection
Box-1	Yes	1	0.919796 m	Yes
Box-2	Yes	1	0.861944 m	Yes
Box-3	Yes	2	0.750835 m	Yes
Paper-1	Yes	1	0	No
Ppaer-2	Yes	2	0	No

F. Result of Angular tilted Sensors

Type	Pothole Detected	Number of Potholes detected	Depth at 15°	Depth at 30°	Depth at 30°
Paper-1	Yes	1	0	0	0
Paper-2	Yes	2	0	0	0
Box-1	Yes	1	0.567902 m	2.098371 m	1.849582 m
Box-2	Yes	1	0.376825 m	1.895637 m	1.639786 m
Box-3	Yes	2	0.285937 m	1.652183 m	1.398972 m

Fig. 21. Detection Result 2

VIII. Technical and Practical limitations

We encountered various inaccuracies in the outputs detected just by the camera sensor. To improve the system's accuracy and performance, we are incorporating a LiDAR sensor to overcome the technical and practical limitations:

- Some areas with stagnant water due to recent rains and spillage or minute dents and shady areas are considered to be potholes.
- The system can only detect the mentioned parameters when the car is traveling within the speed of 35 to 45 km/hr.
- Clusters of small potholes are detected as a single pothole.
- The system can only detect the mentioned parameters when the car is traveling within the speed of 35 to 45 km/hr.
- There were some library compatibility issues with the Lidar Software.
- For the YOLO output, the images were received at 4 fps but the camera-LiDAR output was received at 20 fps.
- The fused sensor output needs to be reduced to match with YOLO frame.
- To merge the outputs, we need additional storage space due to larger size of YOLO outputs.

IX. Conclusion & Future Scope

We have trained the YOLO model to detect potholes in the initial stages. That does not mean it is restricted to just these objects. We can also train a model to detect objects of our interest that are not covered in the pre-trained ones. We have integrated the LiDAR sensor into the system, which provide higher detection accuracy to the system.

The project successfully demonstrates the benefits of using sensor fusion between camera and LiDAR for pothole detection. By combining the strengths of both sensors, the accuracy and reliability of pothole detection were significantly improved. The YOLOv4 AI model was utilized to detect potholes in camera images, and the information was published into the ROS network. This information was then combined with the filtered LiDAR data to confirm the pothole detection. The calibration node was generated to calibrate the values of the LiDAR, which helped in reducing false detections.

The final simulation demonstrated the overlapping of LiDAR scan points on top of the detected pothole, indicating that the pothole was valid. Although two inaccurate pothole detections were found during system testing, the overall performance of the system was satisfactory. The results of the project showed that sensor fusion can enhance the accuracy and reliability of pothole detection, which can have significant implications for road safety and maintenance. This technology can help prevent damage to vehicles and reduce the risk of accidents caused by potholes.

Looking towards the future, there is potential for further improvements in the technology used in this project. For example, incorporating other sensors such as radar or GPS could improve the accuracy of pothole detection and make the system more robust. Additionally, the system could be optimized for real-world applications by testing it on different road surfaces, weather conditions, and lighting environments. Overall, this project has demonstrated the potential of using sensor fusion for pothole detection, and there is significant scope for further research and development in this field.

Acknowledgement

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References

[1] Feihu Zhang, Daniel Clarke, Alois Knoll, "Vehicle detection based on LiDAR and camera fusion", 2014 IEEE 17th International Conference on Intelligent Transportation Systems (ITSC), October 8-11, 2014. Qingdao, China DOI: 10.1109/ITSC.2014.6957925.

[2] Dekui Lv, Xiaxin Yinh, Yanjun Cui, Jianyu Song, Kuidong Qian, Maolin Li, "Research on the technology of LIDAR data processing", The 28th Research Institute of China Electronics Technology Group Corporation, 5th June 2017 Nanjing, China. DOI: 10.1109/EIIS.2017.8298694.

[3] Ramin Sahba, Amin Sahba, Mo Jamshidi, Paul Rad, "3D Object Detection Based on LiDAR Data", 2019 IEEE 10th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), 10-12 October 2019, New York, NY, USA, DOI: 10.1109/UEMCON47517.2019.8993088.

[4] Xingxing Zuo, Patrick Geneva, Woosik Lee, Yong Liu, Guoquan Huang, "LIC-Fusion: LiDAR-Inertial-Camera Odometry", 2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 03-08 November 2019, Macau, China, DOI: 10.1109/IROS40897.2019.8967746.

[5] Nikola Sakic, Momcilo Krunic, Stevan Stevic, Marko Dragojevic, "Camera-LIDAR Object Detection and Distance Estimation with Application in Collision Avoidance System", 2020 IEEE 10th International Conference on Consumer Electronics (ICCE-Berlin), 09-11 November 2020, Berlin, Germany, DOI: 10.1109/ICCE-Berlin50680.2020.9352201.

[6] S. Xie, D. Yang, K. Jiang and Y. Zhong, "Pixels and 3-D Points Alignment Method for the Fusion of Camera and LiDAR Data," in IEEE Transactions on Instrumentation and Measurement, vol. 68, no. 10, pp. 3661-3676, Oct. 2019, doi:10.1109/TIM.2018.2879705.

[7] Kumar, G Ajay, Jin Hee Lee, Jongrak Hwang, Jaehyeong Park, Sung Hoon Youn, and Soon Kwon. 2020. "LiDAR and Camera Fusion Approach for Object Distance Estimation in Self-Driving Vehicles" Symmetry 12, no. 2: 324. https://doi.org/10.3390/sym1202032

[8] S. Pang, D. Morris and H. Radha, "CLOCs: Camera-LiDAR Object Candidates Fusion for 3D Object Detection," 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2020, pp. 10386-10393, doi: 10.1109/IROS45743.2020.9341791.

[9] Thomas, A., Antony, J.K., Isaac, A.V. et al. A novel road attribute detection system for autonomous vehicles using sensor fusion. Int. j. inf. tecnol. 17, 161–168 (2025). https://doi.org/10.1007/s41870-024-02255-5