A Multi-Modal System for Road Detection and Segmentation

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Abstract—Reliable road detection is a key issue for modern Intelligent Vehicles, since it can help to identify the drivable area as well as boosting other perception functions like object detection. However, real environments present several challenges like illumination changes and varying weather conditions. We propose a multi-modal road detection and segmentation method based on monocular images and HD multi-layer LIDAR data (3D point cloud). This algorithm consists of three stages: extraction of ground points from multi-layer LIDAR, transformation of color camera information to an illumination-invariant representation, and lastly the segmentation of the road area. For the first module, the core function is to extract the ground points from LIDAR data. To this end a road boundary detection is performed based on histogram analysis, then a plane estimation using RANSAC, and a ground point extraction according to the point-to-plane distance. In the second module, an image representation of illumination-invariant features is computed simultaneously. Ground points are projected to image plane and then used to compute a road probability map using a Gaussian model. The combination of these modalities improves the robustness of the whole system and reduces the overall computational time, since the first two modules can be run in parallel. Quantitative experiments carried on the public KITTI dataset enhanced by road annotations confirmed the effectiveness of the proposed method.

Keywords—*multi-modal perception, monocular vision, LIDAR, Intelligent Vehicle, road detection*

I. INTRODUCTION

Intelligent Vehicles (IV) constitutes a research focus in recent years with promising benefits to society, including the prevention of accidents, optimal transportation planning and fuel conservation [11]. Among various tasks, IV needs to be able to perform road detection which greatly helps for scene understanding as well as boosting object (pedestrian, vehicle) detection functions by restricting the search space. Moreover, road detection could be an alternative solution for departure warning in cases when lane keeping assistance system fails (e.g. less structured roads without well-defined lane markers). However, it remains a complex task since the algorithm should be able to deal with surrounding objects (e.g. vehicles, pedestrian), different environments (e.g. urban, highways, off-road), road types (e.g. shape, color), and sensor exposure conditions (e.g. varying illumination, different viewpoints and weather conditions) [2]. Many approaches have been proposed in recent decades, using either passive sensors (e.g. vision), or active ones (e.g. LIDAR and RADAR) [2]. Monocular vision based road detection methods usually rely on features in terms of pixel properties such as intensity [5], color [13], [17] or texture [20], [25], [16], [15] and grouping technologies for

segmentation. Among them, color features receive increasing popularity because of their superiority of representing the world and less physical restrictions. To efficiently deal with illumination changes and shadows, several popular color spaces have been introduced including HSI (Hue, Saturation and Intensity) [20], normalized RGB [22] and log-chromaticity space [4]. Stereo vision algorithms not only consider 2D image features but also take advantage of 3D scene information for estimating free space and obstacles using V-Disparity Map techniques [24], [23], [17]. These approaches have improved monocular vision results by the use of a new imaging sensor which grants access to an environment structure prior (i.e. road plane assumption).

The variety of sensors opens a large spectrum of possibilities for the use of multiple perception modalities. Multi-modal road detection presented in [6] combines a camera with a LIDAR sensor. [2] propose an interesting method which uses a Geographical Information Systems (GIS) and a GPS receiver to find the corresponding road patch. Later, this information is combined with the image from a monocular camera to obtain the final result.

Hereafter, a multi-modal system is proposed for road detection and segmentation. Two modalities are used, a monocular vision system and an HD multi-layer LIDAR (i.e. Velodyne). The data of both sensors are analyzed by means of three processing stages (see Fig. 1). The first stage extracts the ground from 3D laser data providing the environment structure prior. The second, transforms the color image into an illumination-invariant gray scale space. Finally, road image regions are obtained by the combination of pre-computed data in a probabilistic framework. The approach, detailed in this paper, addresses the common need of a road feature initialization step in methods using monocular vision [22], [2], [17], [24], [4]. To this end, the state-of-the-art usually assumes the lower part of the image being the road surface. However, this assumption is not respected under important pitch changes and in scenarios with heavy traffic. The latter situation implies that vehicles are quite close to the field of view of the camera limiting the visibility of the road surface. In contrast, our proposed method determines a potential road surface from 3D laser data and exploits this knowledge to identify image road features.

The remainder of this paper is as follows: First, the framework of the algorithm is outlined in Sect. II. The three main stages introduced previous are detailed consecutively in Sect. III, Sect. IV, Sect. V. Experimental results are demonstrated and discussed in Sect. VI. Finally, conclusions and future work are outlined in Sect. VII.
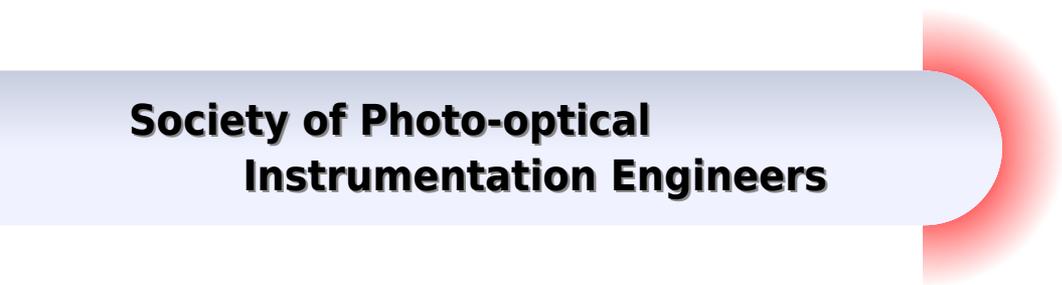
II. MODALITIES OF THE PERCEPTION SYSTEM

The perception set-up assumed for this study, makes use of a monocular vision system mounted facing forward and an HD multi-layer LIDAR installed on the roof of the

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