Enhancing Vehicle Intelligence via Environment Perception and Modeling

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Abstract- **Research and development on environmental perception, advanced sensing, and intelligent driver assistance systems aim at saving human lives. A wealth of research has been dedicated to the development of driver assistance systems and intelligent vehicles for safety enhancement. For the purposes of safety, comfort ability, and saving energy, the field of intelligent vehicles has become a major research and development topic in the world. Many government agencies, academics, and industries invest great amount of resources on intelligent vehicles, such as Carnegie Mellon University, Stanford University, Cornell University, University of Pennsylvania, Oshkosh Truck Corporation, Peking University, Google, Baidu, and Audi. Autonomous vehicles are expected to play a key role in the future of urban transportation systems, as they offer potential for additional safety, increased productivity, greater accessibility, better road efficiency, and positive impact on the environment. Research in autonomous systems has seen dramatic advances in recent years, due to the increases in available computing power and reduced cost in sensing and computing technologies, resulting in maturing technological readiness level of fully autonomous vehicles. The objective of this paper is to provide a general overview of the recent developments in the realm of autonomous vehicle software systems.**

Furthermore, many challenges have been held to test the capability of intelligent vehicles in a real-world environment. Intelligent vehicles are also called autonomous vehicles, driver-less vehicles, or self-driving vehicles. An intelligent vehicle enables a vehicle to operate autonomously by perceiving the environment and implementing a responsive action. It comprises four fundamental technologies: environment perception and modeling, localization and map building, path planning and decision-making, and motion control.

A special attention is paid to methods for lane and road detection, traffic sign recognition, vehicle tracking, behaviour analysis, and scene understanding. In addition, we provide information about data sets, common performance analysis, and perspectives on future research directions in this area.

Index Terms- Intelligent vehicles, environment perception and modeling, lane and road detection, traffic sign recognition, vehicle tracking and behaviour analysis, scene understanding.

I. INTRODUCTION

Many government agencies, academics, and industries invest great amount of resources on intelligent vehicles, such as Carnegie Mellon University, Stanford University, Cornell University, University of Pennsylvania, Oshkosh Truck Corporation, Peking University, Google, Baidu, and Audi.

Intelligent vehicles are also called autonomous vehicles, driverless vehicles, or self-driving vehicles. An intelligent vehicle enables a vehicle to operate autonomously by perceiving the environment and implementing a responsive action. It comprises four fundamental technologies: environment perception and modeling, localization and map building, path planning and decision-making, and motion control.

One main requirement to intelligent vehicles is that they need to be able to perceive and understand their surroundings in real time. It also faces the challenge of processing large amount of data from multiple sensors, such as camera, radio detection and ranging (Radar), and light detection and ranging (LiDAR). A tremendous amount of research has been dedicated to environment perception and modeling over the last decade. For intelligent vehicles, data are usually collected by multiple sensors, such as camera, Radar, LiDAR, and infrared sensors. After pre-processing, various features of objects from the environment, such as roads, lanes, traffic signs, pedestrians and vehicles, are extracted. Both static and moving objects from the environment are being detected and tracked. Some inference can also be performed, such as vehicle behavior and scene understanding. The framework of environment perception and modeling is given. The main functions of environment perception for intelligent vehicles are based on lane and road detection, traffic sign recognition, vehicle tracking and behavior analysis, and scene understanding. In this paper, we present a comprehensive survey of the state-of-the-art approaches and the popular techniques used in environment perception for intelligent vehicles.

The robotization of vehicles has accelerated in recent years. Although the automobile field previously placed importance on the research and development of hardware, that of software has recently been more important. Standardization, generalization, and renewability are needed for efficient research and development of software. However, software platforms for research and education are not sufficiently developed, especially in the automobile field. This study aims to develop a software platform specialized for research on intelligent vehicle systems or for efficient learning, based on robotics technology (RT)-middle-ware developed for robotics. We propose a software module for intelligent vehicle systems using OpenRTM-aist, which is a reference implementation of RT-middle-ware, and then validate its usability. In this paper, the importance of applying RT-middle-ware in the automobile field is explained, and achievements regarding the development of the software module development is discussed. This report presents a comprehensive literature review on environment perception for intelligent vehicles. The state-of-the-art algorithms and modeling methods for intelligent vehicles are given, with a summary of their pros and cons. A special attention is paid to methods for lane and road detection, traffic sign recognition, vehicle tracking, behavior analysis, and scene understanding. In addition, we provide information about data sets, common performance analysis, and perspectives on future research directions in this area. Although the intelligent vehicle can safely drive through the curve with traditional control methods, most of them are to limit the maximum speed according to the curvature of road, which cannot meet the comfortable requirement for passenger.

II. MOTIVATION

An important field of application of robotics has emerged in the last 20 - 25 years which is centered on the automobile, named intelligent vehicles. The automobile has been one of the most important products of the 20th century. It has generated an enormous industry and has given individuals a freedom of movement that has completely changed our ways of living. Indeed, the automobile has been a key factor in the large change in the way our urban societies are structured. Today, there are more than 800 million vehicles on the planet and this number is expected to double in the next ten years. This challenge has led to the development of an active research domain with the ultimate goal of automating the typical tasks that humans perform while driving. An intelligent vehicle is defined as a vehicle enhanced with perception, reasoning, and actuating devices that enable the automation of driving tasks such as safe lane following, obstacle avoidance, overtaking slower traffic. Following the vehicle ahead, assessing and avoiding dangerous situations, and determining the route. The overall motivation of building intelligent vehicles has been to make motoring safer, and more convenient and efficient.

Below points also proved important as a motivation for building intelligent vehicles.

1. Traffic accidents.
2. Military operations.
3. Improve efficiency.
4. Technical challenge.
5. The LAW.

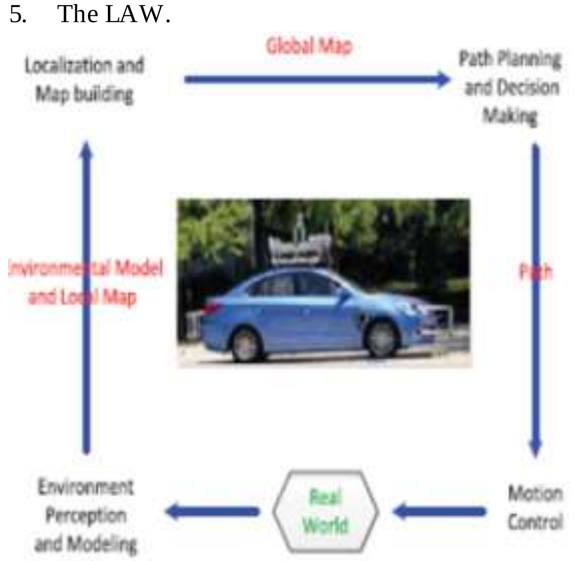


Fig. 2.1: Four fundamental technologies of intelligent vehicle

III. LITERATURE SURVEY

The history of intelligent vehicles has developed over the last two decades. Although the first ideas were born in the 1960s, the level of maturity of the technology at that time did not allow pursuit of the original goal of implementing fully autonomous all-terrain all-weather vehicles. The first documented prototypes of automated vehicles were fielded by a few groups in the military arena in the mid-1980s [51.1âAS3]. The initial stimulus that triggered these innovative ideas was provided by the military sector, which was eager to provide complete automation to its fleet of ground vehicles. It was not before the 1980s that this interest was transferred to the civil sector: governments worldwide launched the first projects, which supported a large number of researchers in these topics. The interest of the automotive industry in developing real products was only triggered after feasibility studies were successfully completed and the first prototypes were demonstrated. Testing of autonomous vehicles on real roads in a real environment was one of the most important milestones in the history of intelligent vehicles. This happened in the mid to late 1990s. First motor vehicles that pioneered the development of intelligent vehicles. In the summer of 1995, the Carnegie Mellon Navlab group ran their No Hands Across America experiment. They demonstrated automated steering, based solely on computer vision, over 98 percent of the time on a 2800-mile trip across the United States. Later in 1995 the Bundeswehr Universität Munich (UBM), Germany fielded a vehicle that was demonstrated with a 1758 km trip from Munich to Copenhagen in Denmark and back. The vehicle was able to drive autonomously for 95 percent of the trip. The car suggested and executed maneuvers to pass other cars. Unlike later robot cars, this car located itself on the current road and followed it until instructed otherwise. It did not localize itself in global coordinates and could drive without Global Positioning System (GPS) and road maps as found in a modern automotive navigation system. The car's trunk was full of transputers and ad hoc hardware.

IV. SYSTEM DESIGN

A. The Framework of Vehicle Tracking and Behavior Analysis

Although there have been substantial developments in the field of vehicle tracking and behavior analysis, the field is still at its infancy stage. The framework of vehicle tracking and behavior analysis is illustrated in Fig. 4.1. From this figure, some features can be used to perform vehicle detection from numerous vehicular sensors. Vehicles can be tracked by many multi-sensor multi-target tracking algorithms. Then, the behavior of vehicles can be inferred.

Fig. 4.1: The framework of vehicle tracking and behavior analysis

1. Vehicle Detection: Research on vehicle detection faces the problem of outdoor complex environments, such as illumination and background changes and occlusions. Key developments on vehicle detection were summarized. The vehicle detection methods can be categorized into appearance-based and motion based.
2. Vehicle Tracking: The aim of vehicle tracking is to re identify and measure dynamics and motion characteristics and to predict and estimate the upcoming position of vehicles [9]. The major problems include: measurement error uncertainty, data association, and necessity to fuse efficiently data from multiple sensors.
3. Behavior Analysis: Using the results from the vehicle detection and tracking system, an analysis of the behaviors of other vehicles can be performed. Four characteristics of vehicle behavior are presented, namely context, maneuvers, trajectories and behavior

classification. Using the results from the vehicle detection and tracking system, an analysis of the behaviors of other vehicles can be performed.

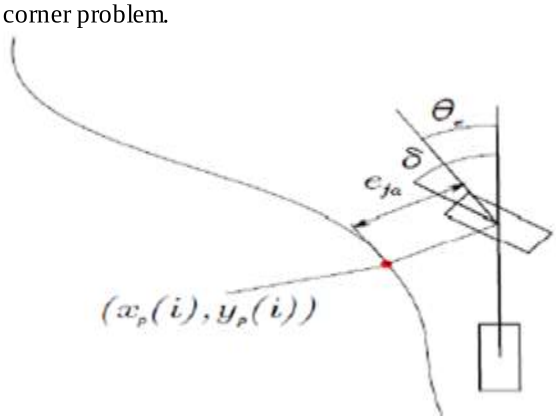
4. Environment Perception: It is a fundamental function to enable autonomous vehicles, which provides the vehicle with crucial information on the driving environment, including the free drivable areas and surrounding obstacles' locations, velocities, and even predictions of their future states. Based on the sensors implemented, the environment perception task can be tackled by using LIDARs, cameras, or a fusion between these two kinds of devices. Some other traditional approaches may also involve the use of short/long-range radars and ultrasonic sensors, which will not be covered in this paper. Regardless of the sensors being implemented, two critical elements of the perception task are (i) road surface extraction and (ii) on-road object detection.

B. Mathematical Model

The look ahead distance is commonly formulated as a function of longitudinal velocity, and saturated at a certain maximum and minimum value, and thus Equation can be rewritten as

$$\mathrm{d(t)} = \tan(-1)\frac{(2L\sin(n(t))}{kv(t))}$$

At lower speed, when the look ahead distance is smaller, the vehicle is expected to track the path closely, and oscillatory behavior is also expected; meanwhile at higher velocity, when the look ahead distance is larger, the vehicle is expected to track the path smoothly, however this will result in the cutting corner problem.



The algorithm has been proven to exponentially converge to zero cross track error. Compared to the pure pursuit method, the Stanley method, has better tracking results and does not cut corners as it uses cross track error and yaw heading error information of the vehicle with respect to the path as measured from the front axle rather than pursuing a point that is located at a certain distance ahead of the vehicle. It also performs better at high speed driving as compared against the pure pursuit method.

V. CONCLUSION AND DISCUSSION

Current challenges for environment perception and modeling technology are due to the complex outdoor environments and the need of efficient methods for their perception in real time. The changeable lighting and weather conditions, and the complex backgrounds, especially the presence of occluding objects still represent significant challenges to intelligent vehicles. Furthermore, it is very important to recognize road in the off-road environment.

As many algorithms have been proposed for environment perception, it is necessary to establish more benchmarks and performance evaluations on environment perception for intelligent vehicles.

Since environment perception and modeling technology stage is the link with the work of localization and map building, path planning and decision-making, and motion control, the next step is to develop the entire system.

Aided by the increase in availability and reduction in cost of both computing power and sensing equipment, autonomous driving technologies have seen rapid progress and maturation in the past couple of decades. This paper has provided a glimpse of the various components that make up an autonomous vehicle software system, and capture some of the currently available state of the art techniques. This paper is by no means a comprehensive survey, as the amount of research and literature in autonomous vehicles has increased significantly in the last decade. However, there are still difficult challenges that have to be solved to not only increase the autonomous driving capabilities of the vehicles, but also to ensure the safety, reliability, and social and legal acceptability aspects of autonomous driving. Environmental perception systems can be made more robust though sensor fusion, where we expect further development in this area to more fully make use of all information provided by the sensors. Also, while newly developed deep learning algorithms for object detection have achieved great performance boosts, they have yet to be extended to operate over fused sensor data from multiple sensor source types.

While impressive capabilities have also been demonstrated in the realm of planning algorithms, we anticipate further advancement to improve real-time planning in dynamic environments. Recent related research is progressing toward better inclusion of robot differential motion constraints and efficient strategies for knowledge retention between subsequent iterations of re-planning. There has been significant theoretical progress in the field of autonomous vehicle control in recent years. However, many of the breakthrough results have only been tested in simulation. Ensuring that the autonomous system robustly follows the intention of higher-level decision-making processes is crucial. Model Predictive Control (MPC) based techniques have been an active research topic in this area, due to its flexibility and performance. Computational time is essential in real time applications, and therefore model selection and MPC problem formulation varies from one application to another. It has been shown that vehicle cooperation can enable better performance in perception and planning modules, however there is much room for advancement to improve the scalability of multi-vehicle cooperative algorithms. Furthermore, although hardware is being standardized for V2V communications, no standard yet exist for what information content should be passed between vehicles.

Autonomous vehicles are complex systems. It is therefore more pragmatic for researchers to compartmentalize the AV software structure and focus on advancement of individual subsystems as part of the whole, realizing new capabilities through improvements to these separate subsystems. A critical but sometimes overlooked challenge in autonomous system research is the seamless integration of all these components, ensuring that the interaction between different software components are meaningful and valid. Due to overall system complexity, it can also be difficult to guarantee that the sum of local process intentions results in the desired final output of the system. Balancing computational resource allotments amongst the various individual processes in the system is also a key challenge. Recognizing the fast pace of research advancement in AVs, we eagerly anticipate the near future developments which will overcome the cited challenges and bring AVs to greater prevalence in urban transportation systems.

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