Guest Editorial
Introducing Perception, Planning, and Navigation for Intelligent Vehicles

RESEARCH activities in intelligent vehicles, and, more broadly, in the intelligent transportation field, have significantly grown over the past two decades. Some earlier efforts were primarily pursued as military or defense-related projects (particularly in the U.S.). In the early 1990s, various government transportation agencies and automobile manufacturers started supporting research initiatives in the intelligent transportation areas. Professor P. Varaiya's paper [1], which was aptly titled "Smart Automobiles on Smart Highways," provides a very good review of the early research in the field. Basically, the research emphasis was on realizing autonomous travel on carefully instrumented road infrastructure and vehicles. These studies resulted in the development of a better appreciation for the difficult issues associated with the demands placed on the infrastructure, performance, and reliability of the communication channels, robust sensory systems, and requirements for reliable perception, planning, and control systems. Growing research activities in the field justified the need for a new technical publication devoted to this area, i.e., that of the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS (ITS) in 2000. In its first year of publication, IEEE-ITS TRANSACTIONS published two special issues: one dealing with intelligent transportation infrastructure [2] and another dealing with research activities in intelligent vehicles [3]. The main emphasis of these contributions highlighted the importance of sensing and perception systems required in intelligent vehicles, such as for road, lane, obstacle, and pedestrian detection. Research and development efforts in these sensing modules have enabled the introduction of adaptive cruise control, lane-departure warning, lane-keeping assistance, and various precrash safety systems.

Research activities in the intelligent vehicle field over the past five years have been very substantial and are rapidly developing. Advances in embedded processors and sensors, in-vehicle networks, and reliable software architectures serve as the main impetus for innovations in enhancing the level of intelligence in vehicles. It is becoming clear that innovations need to consider a systems approach, where sensing, control, and planning are all properly integrated [4]–[6]. Research efforts continue with the clear objective of developing fully autonomous automobiles. Noteworthy among them are those sponsored by the U.S. Department of Defense, which have resulted in well-publicized demonstrations [7]–[9]. In addition, European projects such as "Cybercars" have resulted in the deployment of driverless vehicles at airports and other well-planned urban environments [10], [11]. In contrast with the foregoing projects toward driverless operation, an important research trend with emphasis on keeping the "driver in the loop" has also developed solid traction in the research community. These efforts, which were pursued by major automobile manufacturers and university researchers, have led to "human-centered" frameworks for intelligent vehicles [12], [13]. These activities require multidisciplinary collaboration involving engineering [14], computer and cognitive sciences [15], [16], and psychology and human factor teams [17], [18].

This Special Section traces its origin to the Workshop on Planning, Perception, and Navigation for Intelligent Vehicles organized during the IEEE International Conference on Robotics and Automation in April 2007 in Rome, Italy. The workshop proceedings were successful, and a Special Section of the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS dealing with the same theme was planned. A call for papers was issued. The papers accepted after rigorous review and revision cycle are included in this Special Section.

The nine papers that appear in this Special Section deal with topics that are important in the design and development of intelligent vehicles. These papers can be discussed in four categories.

I. NAVIGATION, LEARNING, AND PLANNING

In the paper by Grisetti *et al.*, entitled "Non-linear Constraint Network Optimization for Efficient Map Learning," the authors present an extension of the former work of Olson on simultaneous localization and mapping based on the graph slam algorithm. The algorithm targets the full 3-D slam problem by proposing a novel parameterization based on a tree structure that makes the complexity of the algorithm dependent on the size of the map instead of the length of the trajectory. The result is an algorithm that keeps the advantages of the incremental approach of Olson while overcoming its most significant drawbacks. The paper presents extensive experimental results with real and simulated data by comparing the proposed approach against three existing methods. The experiments show that, in all cases, the proposed approach converges faster and yields more accurate maps than the other approaches.

The second paper in this category by Vasquez *et al.*, entitled "Incremental Learning of Statistical Motion Patterns with Growing Hidden Markov Models," addresses the general problem of predicting the future motions of some dynamic potential

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obstacles. More precisely, the contribution of the paper is to propose a novel approach for the incremental learning of statistical motion patterns with growing hidden Markov models. Their work aims to learn motion models for vehicles and pedestrians from data coming from sensors, such as visual tracking systems. The approach uses an extension to hidden Markov models that permits incremental learning of the model parameters and structure, and at the same time, the model is being used to predict motion. The authors propose an original way of modeling intentions by including the object-intended position, together with traditional state variables, such as speed and pose. The results they obtained with real and simulated data show that the approach is able to run at camera frame rate and that it produces accurate predictions even for extended time horizons.

II. Perception for Localization and Navigation

Courbon *et al.*, in their paper "Autonomous Navigation of Vehicles from a Visual Memory based on the Use of Generic Camera Model," have developed a vision-based framework for localization and autonomous navigation that enables a vehicle to follow a visual path built during a learning stage. The method can be divided in the following three steps: 1) visual memory building; 2) localization; and 3) autonomous navigation. In the first step, a sequence of images is acquired by driving the vehicle around the environment. Key views are stored and indexed on visual paths that compose the visual memory of the environment. The second step is the self-localization that is based on finding the image of the memory that best fits the current image by comparing preprocessed and online-acquired images. The last step is the navigation. Given the visual memory and the current robot localization, a visual route to be followed by the vehicle to reach its goal is established. A vision-based control approach that takes into account the nonholonomic constraints of the vehicle is proposed. Experimental results with an electric vehicle navigating in an outdoor environment, showing the validation of the approach, are reported.

The second paper in this category is by Fang *et al.*, entitled "Ground Texture Based Localization for Intelligent Vehicles." The authors have developed an approach for the localization of vehicles using ground texture. Although accurate localization can be achieved by using real-time kinematic (RTK) GPS, it may be unfeasible if every vehicle has to be equipped with such an expensive sensor. This paper proposes a ground-texture-based map-matching approach to address the localization problem. The approach they proposed has two steps: 1) mapping and 2) localization. RTK-GPS is only used in mapping, and other sensor data from camera and odometry are synchronously captured to create a global ground texture map. A multiple-view registration-based optimization algorithm is applied to improve the accuracy of the map. In the localization step, vehicle pose is estimated by matching the current camera frame with the best submap frame and by a fusion strategy. Results with both synthetic and real experiments prove the feasibility and effectiveness of the proposed approach.

The last paper in this category is by Schleicher *et al.*, entitled "Real-Time Hierarchical Outdoor-SLAM Based on Stereovision and GPS Fusion." The authors have developed a real-time hierarchical (topological/metric) simultaneous localization and mapping (SLAM) system. It can be applied to the robust localization of a vehicle in large-scale outdoor urban environments, improving the current vehicle navigation systems, most of which are only based on GPS. Then, it can be used on autonomous vehicle guidance with recurrent trajectories (bus journeys, theme parks internal journeys, etc.). It is exclusively based on the information provided by both a low-cost wide-angle stereo camera and a low-cost GPS. The proposed approach divides the whole map into local submaps identified by the so-called fingerprints (vehicle poses). In this submap level (low-level SLAM), a metric approach is carried out. There, a 3-D sequential mapping of visual natural landmarks and the vehicle location/orientation are obtained using a top-down Bayesian method to model the dynamic behavior. GPS measurements are integrated within this low level, which improves the vehicle positioning. A higher topological level (high-level SLAM) based on fingerprints and the multilevel relaxation algorithm has been added to reduce the global error within the map, keeping real-time constraints. This level provides nearly consistent estimation, keeping a small degradation with GPS unavailability. Some experimental results for large-scale outdoor urban environments are presented, showing an almost constant processing time.

III. Perception for Pedestrian Collision Avoidance

The first paper in this category is by Nedevschi *et al.*, entitled "Stereo Based Pedestrian Detection for Collision Avoidance Applications." A new approach is proposed for pedestrian detection using grayscale stereo cameras mounted on board a vehicle, which are capable of detecting pedestrians in urban scenarios. The novelty of the system particularly consists of the combination of 2-D image intensity information, 3-D dense stereo information, and motion features. The 3-D data are used for pedestrian hypothesis generation, scale and depth estimation, and 2-D model selection. A motion–validation method processed in 3-D space is used for eliminating false positives among walking pedestrians. The motion field being computed in 3-D allows the detection of pedestrians walking in any direction. The approach is suited for real-time implementations and was designed to work as a precrash sensor on board road vehicles.

In "An Experimental Study on Pitch Compensation in Pedestrian Protection Systems for Collision Avoidance and Mitigation," Llorca *et al.* present two pitch compensation methods, which have been developed and experimentally tested, aiming to improve pedestrian detection for collision-avoidance and collision-mitigation applications. Two main advantages by means of pitch compensation are reported: 1) The accuracy of the time-to-collision estimation in car-to-pedestrian accidents is increased, and 2) lower false-positive and false-negative detection rates are achieved. The proposed algorithms have been implemented in an on-board stereovision-based pedestrian-detection system. Field tests of the system are reported using two vehicles, where experiments have been carried out concerning collision-avoidance and collision-mitigation applications.

In a paper by Hussein *et al.*, entitled "A Comprehensive Evaluation Framework and a Comparative Study for Human Detectors," a framework for evaluating human detectors geared toward practical deployment is presented. The utility of the evaluation framework is analyzed through its application to two state-of-the-art cascade-based human detectors on two data sets: 1) the INRIA person data set and 2) a local data set of near-infrared images. In this scope, a study that compares between the typically used evaluations on cropped windows and the more practical evaluation on full images using multisize sliding window scanning is provided.

IV. HUMAN-CENTERED DRIVER ASSISTANCE SYSTEMS

The final paper of the issue deals with the important topic of human-centered framework in developing driver-assistance systems. Driver behavioral cues may present a rich source of information and feedback for future intelligent advanced driver-assistance systems (ADAS). The paper by Doshi and Trivedi, entitled "On the Roles of Eye Gaze and Head Dynamics in Predicting Driver's Intent to Change Lanes," deals with an interesting study that compares the roles of eye gaze and head dynamics in predicting the driver's intent to change lanes. With the design of a simple and robust ADAS in mind, they are interested in determining the most important driver cues for distinguishing driver intent. Eye gaze may provide a more accurate proxy than head movement for determining driver attention, whereas the measurement of head motion is less cumbersome and more reliable in harsh driving conditions. The authors use a lane-change intent prediction system to determine the relative usefulness of each cue for determining intent. Various combinations of input data are presented to a discriminative classifier, which is trained to output a prediction of probable lane-change maneuver at a particular point in the future. Quantitative results from a naturalistic driving study are presented and show that head motion, when combined with lane position and vehicle dynamics, is a reliable cue for lane-change intent prediction. The addition of eye gaze does not improve performance as much as simpler head dynamics cues.

In summary, the nine papers included in this Special Section present contributions to various perception-, planning-, and navigation-related issues, which need to be addressed in the development of intelligent vehicles. Some of these are pursued for fully autonomous vehicles, whereas some others are developed for assisting a driver in critical situations to avoid collisions or accidents. It is our hope that readers will find this collection useful in their own research or applications.

Finally, the guest editors of the Special Section would like to express their sincere appreciation to many individuals who contributed to the development of this issue. First, we thank the authors for submitting and revising their papers in a careful and timely manner. Second, we thank a collection of over 30 individuals who served as expert reviewers and offered critical and constructive comments to help the authors and the editors. We also thank Professor A. Broggi, the former Editor-in-Chief (EIC), and Professor F.-Y. Wang, the current EIC of the IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, for their encouragement. Finally, we thank Dr. S. Berte, the Managing Editor for these TRANSACTIONS, for prompt and professional assistance.

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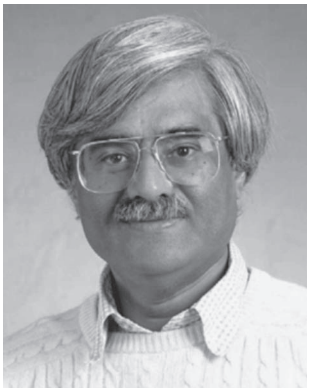

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