Federal Highway Administration

Initial Stage Reference Search

The initial stage investigation is the beginning step in the Exploratory Advanced Research (EAR) Program process for exploring ideas across traditional and nontraditional fields of research and stimulating new approaches to problem solving. The process starts with a literature review and reference scanning to get a better understanding of active research in a particular topic area. The EAR Program annually explores 20 or more topics.

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Visual requirements for human drivers and autonomous vehicles

Identification of published literature between 1995 and 2013, focusing on determining the quantity and quality of visual information needed under both driving modes (i.e., human and autonomous) to navigate the road safely, especially as it pertains to two-lane, curved, rural roads at night.

TOPIC

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U.S. Department of Transportation
Federal Highway Administration

REFERENCE RESULTS: AUTONOMOUS VEHICLES AND ADVANCED DRIVING ASSISTANCE SYSTEMS

A fault-tolerant steering control design for automatic path tracking in autonomous vehicles

Author(s): Fekih, Afef;[1] Devariste, Darlene[1]
Year: 2013
Source: Proceedings of the American Control Conference, pp. 5146–5151
Publisher: IEEE
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In this paper, the authors propose a model reference-based adaptive controller with look-ahead technology for the automatic steering of autonomous vehicles in the presence of actuator faults. Following fault detection by an adaptive diagnostic observer, the proposed controller adaptively changes the control technique to compensate for the loss of actuator effectiveness. The proposed method was applied to a ground vehicle following a rigid square-wave–shaped road under different faulty conditions in the steering actuator. Simplicity of the overall scheme, the speed by which the system is able to recover from the fault, and excellent tracking performance under faulty conditions are the main positive features of the proposed approach.

Sensor-based autonomous color line follower robot with obstacle avoidance

Author(s): Hasan, Kazimahmud;[1] Al-Nahid, Abdullah;[1] Reza, K.J.;[2] Khatun, S.;[2] Basar, M.R.[2]
Year: 2013
Source: BEIAC 2013—2013 IEEE Business Engineering and Industrial Applications Colloquium, pp. 598–603
Publisher: IEEE
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The authors introduce the multiple source Multiple Destination Robot (MDR-1), which has the ability to choose a desired line among multiple lines autonomously. Every line has different colors as their identities. The robot can differentiate among various colors and choose a desired one to find its target. Unlike any other simple line-follower robot, this robot can be considered as a true autonomous line-follower robot that has the ability to detect the presence of an obstacle on its path. A powerful closed-loop control system is used in the robot. The robot senses a line and endeavors itself accordingly toward the desired target by correcting the wrong moves using a simple feedback mechanism and very effective closed-loop system. The robot is capable of following congested curves as it receives the continuous data from the sensors.

A method of road recognition based on LIDAR echo signal

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Year: 2013
Source: Lecture Notes in Electrical Engineering, vol. 210, pp. 397–406
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Road recognition technology is a difficult area of unmanned vehicle for autonomous navigation. Considering the practical application of the driving environment, the authors propose a method of road recognition based on laser infrared radar (light detection and ranging (LIDAR)) of an unmanned vehicle. First, a clustering analysis with the radar echo intensity data was processed. Second, the road was divided into region of interest (ROI) and non-ROI, combined with the radar distance information. Third, the road information was managed by the method of "straights fitting curve" to accomplish the road recognition in real time. The tests on running vehicles show that the proposed method of road recognition can work efficiently in real traffic environments.

Dynamic and safe path planning based on support vector machine among multiple moving obstacles for autonomous vehicles

Author(s): Do, Quoc Huy;[1] Mita, Seiichi;[1] Nejad, Hossein Tehrani Nik;[1] Han, Long[1]
Year: 2013
Source: IEICE Transactions on Information and Systems, vol. E96-D, no. 2, pp. 314–328
Publisher: IEICE
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The authors propose a practical local and global path-planning algorithm for an autonomous vehicle or a car-like robot in an unknown semistructured (or unstructured) environment, where obstacles are detected online by the vehicle's sensors. The algorithm utilizes a probabilistic method based on particle filters to estimate the dynamic obstacles' locations, a support vector machine to provide the critical points, and Bézier curves to smooth the generated path. The generated path safely travels through various static and moving obstacles and satisfies the vehicle's movement constraints. The algorithm is implemented and verified on simulation software. Simulation results demonstrate the effectiveness of the proposed method in complicated scenarios that posit the existence of multiple moving objects.

Fusion of 3-D–LIDAR and camera data for scene parsing

Author(s): Zhao, Gangqiang;[1] Xiao, Xuhong;[2] Yuan, Junsong;[1] Ng, Gee Wah[2]
Year: 2013
Source: Journal of Visual Communication and Image Representation
Publisher: Elsevier
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Fusion of information gathered from multiple sources is essential to build a comprehensive situation picture for autonomous ground vehicles. In this paper, the authors describe an approach that performs scene parsing and data fusion for a 3-D–light detection and ranging (LIDAR) scanner (Velodyne HDL-64E) and a video camera. First, the authors propose a geometry segmentation algorithm for detection of obstacles and ground areas from data collected by the Velodyne scanner. Then, corresponding images collected by the video camera are classified patch by patch into more detailed categories. After that, parsing results of each frame are obtained by fusing the result of Velodyne data and that of the image by using the fuzzy logic inference framework. Finally, parsing results of consecutive frames are smoothed by the Markov random field-based temporal fusion method. This proposed approach has been evaluated with datasets collected by an autonomous ground vehicle testbed in both rural and urban areas. The fused results are more reliable than those acquired via analysis of only images or Velodyne data.

A robust lane-detection method for autonomous car-like robot

Author(s): Sun, Tao;[1] Tang, Shuming;[1] Wang, Jinqiao;[2] Zhang, Weibin[3]
Year: 2013
Source: Proceedings of the 2013 International Conference on Intelligent Control and Information Processing, ICICIP 2013, pp. 373–378
Publisher: IEEE
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As a result of illumination variation, view changes, and complex road conditions, automatic lane detection is crucial for path finding and planning for autonomous car-like robots. In this paper, the authors propose a robust lane-detection method. First, to extract the edges of lanes in traffic scenarios, the authors adopt an adaptive thresholding strategy to binarize a gradient image and trace edges by using their local gradient information. Moreover, by integrating gradient constraints and introducing a reverse voting strategy to the standard Hough transform, the authors greatly improved the speed and stability of line extraction. Further, through inverse perspective mapping the endpoints of extracted lines to the world coordination, the authors could combine the extracted lines from different cameras. Finally, the lane could be detected by matching two points instead of two parallel lines in parameter space. Extensive experiments and comparisons show the efficiency of the proposed method.

Toward driving autonomously: Autonomous cruise control in urban environments

Author(s): Kohlhaas, Ralf;[1] Schamm, Thomas;[1] Lenk, Dominik;[1] Zollner, J. Marius[1]
Year: 2013
Source: IEEE Intelligent Vehicles Symposium, Proceedings, pp. 109–114
Publisher: IEEE
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For automatic driving, vehicles must be able to recognize their environment and take control of the vehicle. The vehicle must perceive relevant objects, including other traffic participants and infrastructure information; assess the situation; and generate appropriate actions. This work is a first step of integrating previous works on environment perception and situation analysis toward automatic driving strategies. The authors present a method for automatic cruise control of vehicles in urban environments. The longitudinal velocity is influenced by the speed limit, the curvature of the lane, the state of the next traffic light, and the most relevant target on the current lane. The necessary acceleration is computed with respect to the information, which is estimated by an instrumented vehicle.

A transferable belief model applied to LIDAR perception for autonomous vehicles

Author(s): Domínguez, Raúl;[1] Alonso, Javier;[2] Onieva, Enrique;[3] González, Carlos[1]
Year: 2013
Source: Integrated Computer-Aided Engineering, vol. 20, no. 3, pp. 289–302
Publisher: IOS Press
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Light detection and ranging (LIDAR) sensors are commonly used in perception for autonomous vehicles because of their high accuracy, speed, and range. These characteristics make the sensor suitable for integration into the perception layer of controllers, which have the capacity to avoid collisions with unpredicted obstacles. The authors' objective was to design a robust and efficient algorithm to acquire useful knowledge from LIDAR scans and to test their performance in real road situations. The method is based on the construction of an occupancy grid based on the Transferable Belief Model, which has proved promising in other studies. Two clear advantages of this method are the reduction of the problem complexity in the phases of segmentation—occlusion detection and tracking—and its ease of integration with other sensors to allow the overall system to evolve toward reliable and complete perception.

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3-D curve lane detection and tracking system based on stereovision

Author(s): Gao, Feng;[1] Jiang, Dawei;[1] Xu, Guoyan;[1] Cui, Ying;[1] Wang, Xiaowei[1]
Year: 2012
Source: CICTP 2012: Multimodal Transportation Systems—Convenient, Safe, Cost-Effective, Efficient. Proceedings of the 12th COTA International Conference of Transportation Professionals, pp. 1247–1258
Publisher: American Society of Civil Engineers
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Lane detection is a crucial issue for advanced driving assistance systems, as well as for autonomous vehicle guidance functions. It is required to have high real-time performance and reliability to avoid lane departure. Taking the curve road as the main interest field, the authors present a 3-D curve lane model to detect, track, and reconstruct real roads based on stereovision. The stereovision algorithm defines the 3-D curve lane as the vertical and horizontal clothoid, which allows elimination of the common assumption: rectilinear lane, flat road, or constant pitch angle. To accurately detect and match the curve lane, the authors propose an improved real-time region-of-interest setup algorithm. The successive detection results are used to estimate the lane model parameters through Kalman filtering. The experiments show that the algorithm proposed has good real-time performance and robustness.

Intelligent robotic car for autonomous navigation: Platform and system architecture

Author(s): Fernandes, Leandro C.;[1] Souza, Jefferson R.;[1] Shinzato, Patrick. Y.;[1] Pessin, Gustavo;[1] Mendes, Caio C. T.;[1] Osório, Fernando S.;[1] Wolf, Denis F.[1]
Year: 2012
Source: Proceedings—2012 2nd Brazilian Conference on Critical Embedded Systems, CBSEC 2012, pp. 12–17
Publisher: IEEE
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The authors present the platform and system architecture of an intelligent vehicle, presenting the control system modules that allow the vehicle to navigate autonomously. The authors' research group works on autonomous navigation and driver assistance systems by using the CaRINA I platform to experiment and to validate data. The authors' platform includes mechanical vehicle adaptations, the development of embedded software architecture, and its practical implementation. The authors' address in detail the sensing and acting infrastructure. Several experimental tests have been conducted to evaluate both platform and proposed algorithms.

Environment-detection-and-mapping algorithm for autonomous driving in rural or off-road environments

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Year: 2012
Source: IEEE Transactions on Intelligent Transportation Systems, vol. 13, no. 2, pp. 974–982
Publisher: IEEE
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The authors present an environment-detection-and-mapping algorithm for autonomous driving that is provided in real time and for both rural and off-road environments. Environment-detection-and-mapping algorithms have been designed to consist of two parts: (1) a lane-, pedestrian-crossing–, and speed-bump– detection algorithm that uses cameras and (2) an obstacle-detection algorithm that uses light detection and ranging (LIDAR) instruments. The lane-detection algorithm returns lane positions by using one camera and the vision module VisLab Embedded Lane Detector (VELD), and the pedestrian-crossing– and speed-bump–detection algorithms return the position of pedestrian crossings and speed bumps. The obstacle-detection algorithm organizes data from LIDARs and generates a local obstacle position map. The designed algorithms have been implemented on a passenger car by using six LIDAR instruments, three cameras, and real-time devices, including personal computers. Vehicle tests were conducted, and test results showed that the vehicle can reach the desired goal with the proposed algorithm.

A cloud-assisted design for autonomous driving

Author(s): Kumar, Swarun;[1] Gollakota, Shyamnath;[1] Katabi, Dina[1]
Year: 2012
Source: Proceedings of the First Edition of the MCC Workshop on Mobile Cloud Computing
Publisher: Association for Computing Machinery
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The authors present Carcel, a cloud-assisted system for autonomous driving. Carcel enables the cloud to have access to sensor data from autonomous vehicles as well as the roadside infrastructure. The cloud assists autonomous vehicles that use this system to avoid obstacles, such as pedestrians and other vehicles, which may not be directly detected by sensors on the vehicle. Further, Carcel enables vehicles to plan efficient paths that account for unexpected events, such as road work or accidents. The authors evaluated a preliminary prototype of Carcel on a state-of-the-art autonomous driving system in an outdoor testbed including an autonomous golf car and six iRobot Create™ robots. Results show that Carcel reduces the average time vehicles need to detect obstacles, such as pedestrians, by 4.6 times compared with today's systems that do not have access to the cloud.

Autonomous ground vehicles: Concepts and a path to the future

Author(s): Luettel, Thorsten;[1] Himmelsbach, Michael;[1] Wuensche, Hans-Joachim[1]
Year: 2012
Source: Proceedings of the IEEE, vol. 100
Publisher: IEEE
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Autonomous vehicles promise numerous improvements to vehicular traffic: an increase in both highway capacity and traffic flow because of faster response times, less fuel consumption and pollution thanks to more foresighted driving, and hopefully fewer accidents thanks to collision avoidance systems. In addition, drivers can save time for more useful activities. In order for these vehicles to safely operate in everyday traffic or in harsh off-road environments, a multitude of problems in perception, navigation, and control have to be solved. This paper gives an overview of the most current trends in autonomous vehicles, highlighting the concepts common to most successful systems as well as their differences. It concludes with an outlook into the promising future of autonomous vehicles.

Automatic road environment classification

Author(s): Tang, Isabelle;[1] Breckon, Toby P.[2]
Year: 2011
Source: IEEE Transactions on Intelligent Transportation Systems, vol. 12, no. 2, pp. 476–484
Publisher: IEEE
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The ongoing development of autonomous vehicles and adaptive vehicle dynamics present in many modern vehicles has generated a need for road environment classification, that is, the ability to determine the nature of the current road or terrain environment from an onboard vehicle sensor. In this paper, the authors investigate the use of a low-cost camera vision solution capable of urban, rural, or off-road classification based on the analysis of color and texture features extracted from a driver's perspective camera view. A feature set based on color and texture distributions is extracted from multiple regions of interest in this forward-facing camera view and is combined with a trained classifier approach to resolve two road-type classification problems of varying difficulty (off-road, on-road), environment determination, and additional multiclass road environment problems (off-road, urban, major/trunk road, and multilane motorway/carriageway). The authors investigated two illustrative classification approaches, and report the results over a series of real environment data. An optimal performance of ~90 percent correct classification was achieved for the (off-road, on-road) problem at a near real-time classification rate of 1 Hz.

Autonomous vehicle control in the VisLab Intercontinental Autonomous Challenge

Author(s): Broggi, Alberto;[1] Medici, Paolo;[1] Zani, Paolo;[1] Coati, Alessandro;[1] Panciroli, Matteo[1]
Year: 2012
Source: Annual Reviews in Control, vol. 36, no. 1, pp. 161–171
Publisher: Elsevier
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Autonomous driving is one of the most interesting fields of research, with a number of important applications, like agricultural, military, and most significantly, safety. The authors address the problem of designing a general purpose path planner and its associated low-level control for autonomous vehicles operating in unknown environments. Different kinds of inputs, like the results of obstacle detection, ditch localization, lane detection, and global path-planning information, are merged together by using potential fields to build a representation of the environment in real-time. Kinematically feasible trajectories, based on vehicle dynamics, are generated on a cost map. This approach demonstrated both flexibility and reliability for vehicle driving in very different environments, including extreme road conditions. This controller was extensively tested during VIAC, the VisLab Intercontinental Autonomous Challenge, which consisted of a 13,000-km–long test for intelligent vehicle applications. The authors present the results, collected during the development stage and the experiment itself, in the final part of this paper.

Features image analysis for road-following algorithm using neural networks

Author(s): Shinzato, Patrick Yuri;[1] Wolf, Denis Fernando[1]
Year: 2010
Source: IFAC Proceedings Volumes (IFAC—PapersOnline), vol. 7, no. PART 1, pp. 306–311
Publisher: IFAC Secretariat
Author affiliation:
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Navigation is a broad topic that has received considerable attention from the mobile robotic community. To execute autonomous driving outdoors, like streets and roads, it is necessary that the vehicle identify parts of the terrain that can be traversed and parts that should be avoided. The authors describe an analysis of an image-based terrain identification based on different visual information using a multilayer perceptron neural network. The authors conducted experimental tests that use a car and a video camera in real scenarios to evaluate the proposed features and networks.

Radar system on a large autonomous vehicle for personnel avoidance

Author(s): Silvious, Jerry;[1] Wellman, Ron;[2] Tahmoush, Dave;[1] Clark, John[1]
Year: 2010
Source: Proceedings of SPIE—The International Society for Optical Engineering, vol. 7669
Publisher: SPIE
Author affiliation:
[1]U.S. Army Research Laboratory, Adelphi, MD 20783, United States, http://www.arl.army.mil/www/
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The U.S. Army Research Laboratory designed, developed, and tested a novel switched beam radar system operating at 76 GHz for use in a large autonomous vehicle to detect and identify roadway obstructions, including slowly moving personnel. The authors discuss the performance requirements for the system to operate in an early collision avoidance mode to a range of 150 meters and at speeds of over 20 m/s. The authors report the measured capabilities of the system to operate in these modes under various conditions, such as rural and urban environments, and on various terrains, such as asphalt and grass. Finally, the authors discuss the range-Doppler map processing capabilities that were developed to correct for platform motion and to identify roadway vehicles and personnel moving at 1 m/s or more along the path of the system.

Toward urban driverless vehicles

Author(s): Benenson, Rodrigo;[1] Petti, Stephane;[1] Fraichard, Thierry;[1] Parent, Michel[1]
Year: 2008
Source: International Journal of Vehicle Autonomous Systems, vol. 6, no. 1&2, pp. 4–23
Publisher: Inderscience Enterprises Ltd.
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   rocquencourt

This paper addresses the problem of autonomous navigation of a car-like robot evolving in an urban environment. Such an environment exhibits a heterogeneous geometry and is cluttered with moving obstacles. Furthermore, in this context, motion safety is a critical issue. The proposed approach to the problem lies in the design of perception and planning modules that consider explicitly the dynamic nature of the vehicle and the environment while enforcing the safety constraint. The main contributions of this work are the development of such modules and integration into a single application. Initial full-scale experiments validating the approach are presented.

Autonomous automobiles: Developing cars that drive themselves

Author(s): Ferguson, Dave[1]
Year: 2007
Source: Proceedings—Design Automation Conference, p. 383
Publisher: Association for Computing Machinery, Inc.
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   collaboration.net/

Every year, hundreds of thousands of people are killed in road accidents, with millions more injured. The vast majority of these accidents are due to human error, with less than

10 percent caused by vehicle defects. Such staggering findings motivate the use of driver assistant systems and fully autonomous vehicles to increase driver and passenger safety. The author explores developments in driver assistant systems and autonomous vehicles. In particular, the author focuses on the Urban Challenge competition, in which fully autonomous passenger vehicles will conduct navigation missions in urban environments. The goal of the Urban Challenge is to develop vehicles that can safely drive themselves in realistic urban settings. To succeed, the vehicles must obey traffic laws while safely merging into moving traffic, driving through traffic circles and busy intersections, and parking in parking lots. This represents a significant leap in autonomous vehicle technology and has required advances in sensing, autonomous reasoning, and semiconductor technology. The author discusses some of the challenges involved and provides example results from Carnegie Mellon University's entry into the Urban Challenge.

Coordinated maneuvering of automated vehicles in platoons

Author(s): Michaud, François;[1, 2] Lepage, Pierre;[2] Frenette, Patrick;[2] Létourneau, Dominic;[2] Gaubert, Nicolas[2]
Year: 2006
Source: IEEE Transactions on Intelligent Transportation Systems, vol. 7, no. 4, pp. 437–446
Publisher: IEEE
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To eventually have automated vehicles operate in platoons, it is necessary to study what information each vehicle must have and to whom it must communicate for safe and efficient maneuvering in all possible conditions. The authors formulate the problem in terms of sensing and communicated information. By emulating platoons using a group of mobile robots, the authors demonstrate the feasibility of maneuvers (e.g., entering, exiting, and recuperating from an accident) using different distributed coordination strategies. The coordination strategies studied range from no communication to unidirectional or bidirectional exchanges between vehicles and to fully centralized decisions by the leading vehicle. One particularity of this paper is that instead of assuming that the platoon leader or all vehicles globally monitor what is going on, only the vehicles involved in a particular maneuver are concerned, distributing decisions locally among the platoon. The authors report on experimental trials using robots that have limited and directional perception of other things and that use vision- and obstacle-avoidance sensing. Results confirm the feasibility of the coordination strategies in different conditions and various uses of communicated information to compensate for sensing limitations.

Springrobot: A prototype autonomous vehicle and its algorithms for lane direction

Author(s): Li, Qing;[1] Zheng, Nanning;[1] Cheng, Hong[1]
Year: 2004
Source: IEEE Transactions on Intelligent Transportation Systems, vol. 5, no. 4, pp. 300–308
Publisher: IEEE
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The authors present the current status of the Springrobot autonomous vehicle project, whose main objective is to develop a safety-warning and driver-assistance system and an automatic pilot for rural and urban traffic environments. This system uses a high-precision digital map and a combination of various sensors. The authors briefly describe the architecture and strategy for the system and present the details of lane-marking detection algorithms. The R and G channels of the color image are used to form gray-level images. The size of the resulting gray image is reduced, and the Sobel operator with a very low threshold is used to get a grayscale edge image. In the adaptive randomized Hough transform, pixels of the gray-edge image are sampled randomly according to their weights, which correspond to their gradient magnitudes. The three-dimensional parametric space of the curve is reduced to the two-dimensional and the one-dimensional space. The paired parameters in two dimensions are estimated by gradient directions, and the last parameter in one dimension is used to verify the estimated parameters by histogram. The parameters are determined coarsely, and quantization accuracy is increased relatively by a multiresolution strategy. Experimental results in different road scenes and a comparison with other methods have proven the validity of the proposed method.

Perception for collision avoidance and autonomous driving

Author(s): Aufrère, Romuald;[1, 2] Gowdy, Jay;[1] Mertz, Christoph;[1] Thorpe, Chuck;[1] Wang, Chieh-Chih;[1] Yata, Teruko[1]
Year: 2003
Source: Mechatronics, vol. 13, no. 10 SPEC., pp. 1149–1161
Publisher: IFAC Secretariat
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The Navlab group at Carnegie Mellon University has a long history of developing automated vehicles and intelligent systems for driver assistance. The earlier work of the group concentrated on road following, cross-country driving, and obstacle detection. The new focus is on short-range sensing so as to look all around the vehicle for safe driving. The current system uses video sensing, laser rangefinders, a novel light-stripe rangefinder, software to process each sensor individually, a map-based fusion system, and a probability-based predictive model. The complete system has been demonstrated on the Navlab 11 vehicle for monitoring the environment of a vehicle driving through a cluttered urban environment, and for detecting and tracking fixed objects, moving objects, pedestrians, curbs, and roads.

Real-time lane detection for autonomous navigation

Author(s): Jeong, Seung Gweon;[1] Kim, Chang Sup;[1] Yoon, Kang Sup;[1] Lee, Jong Nyun;[1] Bae, Jongll;[1] Lee, ManHyung[1]
Year: 2001
Source: IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC, pp. 508–513
Publisher: IEEE
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Lane detection, based on a road model or feature, requires accurate information on the lane in the form of an image. It is inefficient to implement a lane-detection algorithm through the full range of an image when it is applied to a real road in real time because of the calculating time. The authors of this paper define two searching ranges of detecting the lane in a road. The first is a searching mode that searches the lane without any prior information of the road. The second searching range is a recognition mode, which is able to reduce the size and change the position of a searching range by predicting the position of a lane through the acquired information in a previous frame. It accurately and efficiently extracts the edge candidate points of a lane conducting without any unnecessary searching. By means of inverse perspective transform that removes the perspective effect on the edge candidate points, the authors transformed the edge candidate information in the image coordinate system into the plane-view image in the world coordinate system. The authors defined the linear approximation filter and removed the faulty edge candidate points by using it. This paper aims to approximate more correctly the lane of an actual road by applying the least-mean square method with the fault-removed edge information for curve fitting.

Autonomous driving on vehicle test tracks: Overview, implementation, and results

Author(s): Schmidt, Rolf;[1] Weisser, H.;[1] Schulenberg, P.;[1] Goellinger, H.[1]
Year: 2000
Source: IEEE Intelligent Vehicles Symposium, Proceedings, pp. 152–155
Publisher: IEEE
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The authors describe the implementation of the cooperative project "Autonomous Driving," which had been set up for the automation of vehicle test drives on the Volkswagen proving ground as introduced previously. As part of the concept, ordinary mass-produced cars can be transformed into automatically driven cars within a few hours by skilled persons. Within the project, two test vehicles were equipped with sensors, computers, and actuators (driving robots). They can be driven by a robot while the sensor system observes the entire surrounding area so as to react to any obstacles. Furthermore, the vehicle control can be overruled by an electronic copilot in case of an emergency.

Robust course-boundary extraction algorithms for autonomous vehicles

Author(s): Roman, Chris;[1] Reinholtz, Charles[1]
Year: 1998
Source: IEEE Intelligent Systems and Their Applications, vol. 13, no. 6, pp. 32–39
Publisher: IEEE
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Practical autonomous robotic vehicles require dependable methods for accurately identifying course or roadway boundaries. The authors have developed a method to reliably extract the boundary line by using simple dynamic thresholding, noise filtering, and blob removal. This article describes their efforts to apply this procedure in developing an autonomous vehicle.

Vision-based guidance for autonomous land vehicle navigation in outdoor road environments with static and moving cars

Author(s): Chen, Kuang-Hsiung;[1] Tsai, Wen-Hsiang[1]
Year: 1998
Source: Proceedings of the National Science Council, Republic of China, Part A: Physical Science and Engineering, vol. 22, no. 5, pp. 691–702
Publisher: National Science Council
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The authors propose a new effective approach to vision-based guidance for autonomous land vehicle (ALV) navigation in outdoor road environments with static and moving cars by using model matching and color information clustering techniques. The conventional way of detecting obstacles and cars in the navigation route, which is in general difficult, is avoided; instead, collision-free road area detection, which is usually easier, is adopted. Road boundaries are used to construct the reference model, and road surface intensity is selected as the visual feature. The pixels in a road image near the two lines that represent the road boundary shape, which are estimated at the beginning of each navigation cycle, are checked to judge whether the left or right lane width has changed due to occlusion caused by nearby static or moving cars on the road. If both lane widths have not changed, model matching is performed immediately to find the ALV location. If either or both lane widths have changed, corresponding processes are performed to find the width of the occluded road, and a model is recreated if the new road width is different from the old one in the previous navigation cycle. Model matching is then performed to locate the ALV on the occluded road. To save computing time, only partial model matching is performed. A turn angle is then computed to guide the ALV to follow the central path line on the extracted road for safe navigation. Various color information on roads is used to extract road surfaces, and a clustering algorithm is used to solve the problem caused by great changes of intensity in navigation environments. Successful navigation tests show that the proposed approach is effective for ALV guidance on common roads with static and moving cars.

Mixed traffic and automated highways

Author(s): Thorpe, Chuck[1]
Year: 1997
Source: IEEE International Conference on Intelligent Robots and Systems, vol. 2, pp. 1011–1017
Publisher: IEEE
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A major issue in building a prototype automated highway system (AHS) is whether the system needs dedicated lanes, occupied only by computer-controlled cars that communicate and cooperate with each other, or whether the automated vehicles can be provided with enough sensing and intelligence that they can safely operate on regular highways, intermixed, with manually driven vehicles. A major portion of the Carnegie Mellon University (CMU) research effort AHS is focused on determining the technical feasibility of operation in mixed traffic. The author outlines the issues of mixed traffic versus dedicated lanes, then describes CMU's efforts in building complete demonstration systems, vehicle sensors, obstacle sensors, car-tracking software, reasoning for tactical driving, and deployment scenarios.

Divergent stereo in autonomous navigation: From bees to robots

Author(s): Santos-Victor, Jose;[1] Sandini, Giulio;[1] Curotto, Francesca;[1] Garibaldi, Stefano[1]
Year: 1995
Source: International Journal of Computer Vision, vol. 14, no. 2, pp. 159–177
Publisher: Springer Verlag
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The authors present some experiments of a real-time navigation system driven by two cameras pointing laterally to the navigation direction (*Divergent Stereo*). Similarly to what has been proposed in Franceschini et al. (1991) and Coombs and Roberts (1992), the authors' approach (Sandini et al., 1992; Santos-Victor et al., 1993) assumes that, for navigation purposes, the driving information is not distance (as it is obtainable by a stereo setup) but motion and, more precisely, by the use of qualitative optical-flow information computed over nonoverlapping areas of the visual field of two cameras. Following this idea, a mobile vehicle was equipped with a pair of cameras looking laterally (much like honeybees) and a controller based on fast, real-time computation of optical flow was implemented. The control of the mobile robot (*Robee*) was based on the comparison between the apparent image velocity of the left and the right cameras. The solution adopted was derived from recent studies (Srinivasan, 1991) describing the behavior of freely flying honeybees and the mechanisms they use to perceive range. This qualitative information (no explicit measure of depth is performed) is used in many experiments to show the robustness of the approach, and a detailed description of the control structure is presented to demonstrate the feasibility of the approach in driving the mobile robot within a cluttered environment. The authors also present a discussion about the potentialities of the approach and the implications in terms of sensor structure.

REFERENCE RESULTS: HUMAN BEHAVIORAL AND COGNITIVE TASK ANALYSIS, CRITICAL DECISIONS, DRIVING TASKS, AND TASK ANALYSIS

Augmenting the driver's view with real-time safety-related information

Author(s): Fröhlich, Peter;[1] Schatz, Raimund;[1] Leitner, Peter;[1] Baldauf, Matthias;[1] Mantler, Stephan[2]
Year: 2010
Source: ACM International Conference Proceeding Series, 2010, Proceedings of the 1st Augmented Human International Conference, AH '10
Publisher: Association for Computing Machinery
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In the last few years, in-vehicle information systems have advanced in terms of design and technical sophistication. This trend manifests itself in the current evolution of navigation devices toward advanced 3-D visualizations as well as real-time telematics services. The authors present important constituents for the design space of realistic visualizations in the car and introduce realization potentials in advanced vehicle-to-infrastructure application scenarios. To evaluate this design space, the authors conducted a driving simulator study, in which the in-car human–machine interface (HMI) was systematically manipulated with regard to its representation of the outside world. The results show that in the context of safety-related applications, realistic views provide higher perceived safety than with traditional visualization styles, despite their higher visual complexity. The authors also found that the more complex the safety recommendation the HMI has to communicate, the more drivers perceive a realistic visualization as a valuable support. In a comparative inquiry after the experiment, the authors found that egocentric and bird's eye perspectives are preferred to top-down perspectives for safety-related in-car safety information systems.

Visual and tactile information to improve drivers' performance

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Year: 2010
Source: Proceedings—IEEE Virtual Reality, pp. 295–296
Publisher: IEEE
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Usually a car is steered by using mainly visual information to perceive a road's shape and bends. The authors developed a driving simulator with visual and/or tactile information guides to virtually present drivers' lateral position and to enhance their steering performance. The purpose of this study was to test effects of the cross-modal guide information on the driving performance. The authors found that the tactile guide improved driving accuracy more than the visual guide without any tradeoff of driving loads. Thus, the tactile information of virtual position of a car is useful for assisting and improving driver's performance with fewer loads.

Age-related physical and emotional characteristics to safety warning sounds: Design guidelines for intelligent vehicles

Author(s): Kim, Man Ho;[1] Lee, Yong Tae;[1] Son, Joonwoo[1]
Year: 2010
Source: IEEE Transactions on Systems, Man, and Cybernetics Part C: Applications and Reviews, vol. 40, no. 5, pp. 592–598
Publisher: IEEE
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Recent technological advances have made motor vehicles more intelligent to increase safety and comfort. An intelligent vehicle provides drivers with safety warning information through audible sounds, visual displays, and tactile feedback; however, elderly drivers often have decreased cognitive and psychomotor abilities in the areas of hearing, eyesight, short-term memory, and spatial perception. As a result, possible age-related deficits should be considered when designing effective warning systems. The authors evaluated the impact of advancing age on a driver's physical responses and emotional preferences with regard to audible safety warnings that are widely used to warn about driving hazards. Three sound characteristics (i.e., frequency, tempo, and intensity) and three age groups (i.e., young, middle-aged, and old) were considered in investigating the effect of age-related hearing loss and reduced speed of movement. Data were collected from 38 drivers who drove on a simulated rural road in a driving simulator. Experimental results showed that age influenced driver's responses and emotional preference. An appropriate range of warning sounds is suggested.

Development of driver-eye fixation analysis system and headlight beam distribution research for actual roads

Author(s): Kamijo, Masayoshi;[1] Kobayashi, Shoji[2]
Year: 2008
Source: Transportation Research Board 87th Annual Meeting
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A vehicle's headlight beam distribution must offer accurate visual information and be set in such a way that ensures a safe and comfortable drive. At present, however, headlight beam distribution is often determined without due regard given to the behavior and area of the driver's eye fixation. As a result, the authors developed a driver-eye fixation analysis system to conduct research into headlight beam distribution. Based on the visual information investigation theory and the kinematic eddy theory of the eyeball, a method to specify an eye fixation point and a method to eliminate noise data, such as looking in another direction, were developed from measured sight line data. By using these methods, a system was developed that produces a map, which indicates behavior and area of eye fixation, the distribution of eye fixation points, gaze frequency, and the distribution of visual information. An analysis of eye fixation while driving on a road in a mountainous area, rural road, urban road, and expressway revealed the following: (a) Analysis of driver-eye fixation behavior while making curves showed that the driver was attempting to

acquire road information three seconds ahead of the vehicle; (b) analysis of gaze area for each type of road showed that the horizontal beam spread areas needed for each one is approximately 35‹ for mountainous area road, 30‹ for the rural and urban roads, and 20‹ for the expressway; and (c) the average focal point distance for each type of road was 54.0 m for the mountainous area road, 63.7 m for the rural road, 51.3 m for the urban road, and 180.9 m for the expressway. The focal point distance was longest for the expressway, where traveling speed was the highest, which revealed that the average focal point distance is affected by which type of road the driver is traveling on.

Effects of adaptive information presentation

Authors: Fricke, Nicola[1]
Year: 2007
Source: Proceedings of the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design
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The author is developing several new approaches to assist drivers in dealing with the complex task of driving. One such approach is to support the driver in dealing with secondary tasks with the aim of facilitating the primary task of driving. In this study, the author tested whether a situation-dependent change of modality presentation for a secondary task can support time-sharing and enhance performance in the primary task. In an experiment, 42 participants were engaged in a computer-simulated tracking task, which is a continuous task, like driving a car. From time to time they also had to perform a decisionmaking task, which was to identify special numerical series. The task was an analogy to receiving a phone call while driving. The independent variables consisted of (1) demands of the situation (low versus high) and (2) presentation modality of the secondary task (visual, auditory, visual plus auditory; adaptive, nonadaptive). Performance was assessed through mistakes in the tracking task (lateral deviation from the central line). In addition, the participants were asked for their subjective opinion of this system-driven change of modality presentation. Findings do not support the assumption that changing from bimodal (visual plus auditory) to auditory-only presentation under high situational demands leads to best performance in the driving task. Rather, auditory-only information presentation was best under all conditions and led to the fewest mistakes in the tracking task. Moreover, subjective ratings revealed that 50 percent of the participants favored auditory-only presentation, and 75 percent of the participants generally preferred nonadaptive information presentation.

Driver task analysis as a tool in traffic safety research and practice

Author(s): Fastenmeier, Wolfgang;[1] Gstalter, Herbert[1]
Year: 2007
Source: Safety Science, vol. 45, no. 9, pp. 952–979
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The authors explain the need for task analysis in the context of car driving, because the interaction between the car drivers' capabilities and the demands of the actual driving

task determines the outcome in terms of a more-or-less safe driving behavior. After reviewing past approaches, the main focus of the study is on the presentation of a new procedure for driving task analysis and driver requirement assessment (SAFE: Situative Anforderungsanalyse von Fahraufgaben). The authors derive a framework for task analysis both from classifications of road traffic situations and a model of the drivers' information processing. The first step of the procedure is to divide a given driving task into subtasks. These subtasks are appointed to defined stretches of the road, and the time structure of the subtasks is determined. For each subtask, an analysis format is used that organizes different requirements into perception, expectation, judgment, memory, decision, and driver action. Then, typical driver errors are attached to the subtasks, and all the information together is compressed to ratings of complexity and risk to derive the crucial subtasks. Finally, the authors present some examples of how the method can be applied and discuss its future usefulness.

The danger of incorrect expectations in driving: The failure to respond

Author(s): Martens, Marieke H.[1]
Year: 2007
Source: Proceedings of the Fourth International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design
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The author addresses *inattentional blindness or look-but-fail-to-see* in driving. How it is possible that visual information, highly relevant for driving, is not perceived or responded to? The author's main focus in this study was on driver expectations. Different experimental studies were performed. The author had drivers perform a driving task in which they had to drive a specific road numerous times. This way, the author was able to control driver expectations within a specific road environment. After some drives, the author made some crucial changes to the road environment (e.g., change in priority, change in no-entry road). Behavioral responses (e.g., speed, deceleration) were measured to these changes, as well as eye movements (e.g., glance duration) and awareness of the changes. All participants were experienced drivers, and over all studies, 250 drivers participated. There was a relationship between driver expectations and the failure to respond. Glance duration to traffic signs was found to decrease with a driver becoming more and more familiar with a specific road. Visually selecting the information seems to be an important condition for enabling a response, but it is certainly not enough. There were various cases in which expectations were so strong that drivers looked at the information but did not respond. There seems to be a high correlation between glance duration and response, as well as between the type of change and response. In-vehicle equipment that warns the driver for these types of situations is highly effective. The author presents an elaborated task performance model.

Before–after comparison of edge line effects on a rural two-lane highway

Author(s): Tsyganov, Alexei R.;[1] Machemehl, Randy B;[1] Warrenchuk, Nicholas M.;[1] Wang, Yue[1]
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Pavement markings have definite functions in a proper traffic control system. They are applied for the purposes of regulating and guiding the movement of traffic and promoting safety without diverting the driver's attention from the roadway. It was observed that pavement markings located to the right of the car are detected more easily and at distances farther away when compared with the corresponding markings placed to the left of the car; however, compared with other types of longitudinal markings, there has been little investigation of the effect of edge lines on safety and driver behavior. Through crash statistical analysis, the authors found that edge line treatments on rural two-lane roadways may reduce accident frequency up to 26 percent, and the highest safety impacts occur on curved segments of roadways with lane widths of 9–10 ft. The next stage of the study focused on complex investigations of edge line impacts on driver behavior and reactions, including vehicle navigational and positioning issues, speed selection, and effect on driver visual perception. The authors conducted stationary traffic observation, test driving, and several laboratory experiments on the selected rural two-lane highways with different roadway widths before and after edge line placement. Studies have indicated that edge line treatments increase speed on average by 5 mph or by 9 percent on both straight and curved highway segments, move vehicles toward the pavement edge at both daylight and darkness in an average of 20 inches, reduce vehicle fluctuation around trajectory center line by 20 percent, reduce driver mental workload, improve driver's estimation of roadway curvature, and increase driver's advance time of intersection identification.

Toward a general theory of driver behavior

Author(s): Fuller, Ray[1]
Year: 2005
Source: Accident Analysis and Prevention, vol. 37, no. 3, pp. 461–472
Publisher: Elsevier
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Taylor (Taylor, D.H., 1964. Drivers' galvanic skin response and the risk of accident. Ergonomics 7, 439–451) argued that drivers attempt to maintain a constant level of anxiety when driving, which Wilde (Wilde, G.J.S., 1982. The theory of risk homeostasis: Implications for safety and health. Risk Analysis 2, 209–225) interpreted to be coupled to subjective estimates of the probability of collision. The author argues in this theoretical paper that what drivers attempt to maintain is a level of task difficulty. Naatanen and Summala (1976. *Road user behavior and traffic accidents.* Elsevier: New York), similarly rejected the concept of statistical risk as a determinant of driver behavior, but in doing so fell back on the learning process to generate a largely automatized selection of appropriate safety margins. It is argued here, however, that driver behavior cannot be acquired and executed principally in such statistical risk terms. The concept of task difficulty is elaborated within the framework of the task-capability interface (TCI) model, which

describes the dynamic interaction between the determinants of task demand and driver capability. It is this interaction that produces different levels of task difficulty. The author discusses implications of the model regarding variation in performance, resource allocation, hierarchical decisionmaking, and the interdependence of demand and capability. The author proposes task difficulty homeostasis as a key subgoal in driving, and speed choice is argued to be the primary solution to the problem of keeping task difficulty within selected boundaries. The relationship between task difficulty and mental workload and calibration is clarified. Evidence is cited in support of the TCI model, which clearly distinguishes task difficulty from estimates of statistical risk; however, contrary to expectation, ratings of perceived risk depart from ratings of statistical risk but track difficulty ratings almost perfectly. It now appears that feelings of risk may inform driver decisionmaking, as Taylor originally suggested, but not in terms of risk of collision but rather in terms of task difficulty. Finally, risk homeostasis is presented as a special case of task difficulty homeostasis.

Context-aware driving behavior model

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Existing driving behavior models have a strong emphasis on the driver's cognitive components, including aspects such as motivation, risk assessment, attention, compensation, capability, workload, individual traits, and experience. Each existing model was designed specifically for a particular driving situation such as speeding or fatigue. A general and comprehensive model is still unavailable despite 60 years of research on the topic. No consensus has been reached mainly due to the inability to generalize, operationalize, and validate these subjective cognitive models in real driving conditions. This paper defines a framework for a new context-aware driving behavior model capable of predicting driver behavior. This approach broadens the cognitive focus of existing driving behavior models to integrate contextual information related to the vehicle, environment, driver, and the interactions between them. The theoretical model is an information-processing, probabilistic-based model. Context awareness concepts from the ubiquitous computing research community are integrated into the model. Such integration improves the descriptive power and generalizability of the driving behavior model.

Field study of driver's curve-detection performance in daytime and nighttime

Author(s): Hagiwara, Toru;[1] Suzuki, Kento;[1] Tokunaga, Roberto A.;[1] Yorozu, Naoki;[1] Asano, Motoki[1]
Year: 2001
Source: Transportation Research Record, no. 1779, pp. 75–85
Publisher: Transportation Research Board
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The authors investigated effects of road scenes and traffic-control devices on driver's curve-detection performance. Field experiments were conducted on a 19-km section of highway running through a hilly area in Hokkaido, Japan. The driver obtained directional information from the road scene ahead and from traffic-control devices at the beginning of the target curve. Road scene characteristics were determined subjectively. Configurations of traffic-control devices at 32 curves were obtained from the road maintenance database and were measured on site for each curve. Each of the 17 participating subjects drove an instrument-equipped vehicle and pressed a button as soon as he or she recognized the direction of the target curve. Detection distance of each curve was measured. The experimenter determined the maximum detection distance (MDD) of each target curve. A curve-detection index, defined as the detection distance divided by the MDD, was used to compare detection performance for each curve. Characteristics of detection performance for the curves were determined by a duster analysis and regression analysis. Curves were classified into five groups according to the results of the cluster analysis. Results of the within-subject regression analysis revealed that subjects driving in the daytime obtained directional information about the curve from the road scene, whereas in the nighttime the lighting midway through the curve had a greater effect on detection performance. Results indicate that visual cues should be considered when traffic-control devices are installed at a curve, and appropriate traffic-control devices should be selected to increase the detection performance of a curve.

Automobiles on horizontal curves: Experiments and observations

Author(s): Felipe, Emmanuel;[1] Navin, Francis[1]
Year: 1998
Source: Transportation Research Record, no. 1628, pp. 50–56
Publisher: Transportation Research Board
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The authors obtained statistical information on the basic variables involved in driving through a horizontal curve by using a 4×4 Latin square design experiment to measure the action of automobile drivers in test track horizontal curves. The independent variables used in the test curves were speed (e.g., comfortable, fast), pavement surface (e.g., dry, wet), driver (e.g., male, female), and curve radius (e.g., 16 m, 26 m, 60 m, 100 m). The measured output was the driver's selected speed and corresponding lateral acceleration. In addition, the passengers indicated their comfort level on a four-point semantic scale. Expert drivers also drove the test curves to establish the upper limits of the driver–vehicle–tire system. Field observations of four curves along a two-lane rural mountain highway

measured driver vehicle speed, lateral acceleration, and lateral position. The results indicate that, for a comfortable ride, drivers are limited by their comfortable lateral acceleration on small radius curves and seek the "environmental speed" on large radius curves.

From managing the car to managing the road: The development of driving skills

Author(s): Klein, Helen Altman;[1] Vincent, Eric John;[1] Isaacson, Judith J.[1]
Year: 1998
Source: Proceedings of the Human Factors and Ergonomics Society, vol. 2, pp. 1271–1275
Publisher: Human Factors and Ergonomics Society, Inc.
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Skilled driving requires complex cognitive and recognitional abilities. The authors used a cognitive task analysis and a low-tech simulation to study experience-linked differences in these abilities. Inexperienced (n = 18) and experienced (n = 17) drivers participated. The inexperienced drivers struggled with control. They worked to keep their car between the lines and to execute turns. In time, automatized performance replaced conscience control. Some situations, like icy roadways, were automatized later than others. As driving reached automaticity, drivers began attending to a wider range of cues. They predicted and avoided problems. A broader view of the roadway emerged in parallel with the development of anticipation. The authors also observed that experienced drivers were more likely to know their limits and adopted effective compensatory strategies. The Dreyfus and Dreyfus (1986) model of expertise was used to describe these systematic changes. Protocol analysis suggested guidelines for training novice drivers and for upgrading skills of long-term drivers.

Traffic-sign–reading distances and times during night driving

Author(s): Zwahlen, Helmut T.[1]
Year: 1995
Source: Transportation Research Record, no. 1495, pp. 140–146
Publisher: Transportation Research Board
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Videotaped eye fixations and saccades (30 frames per second) were analyzed for 32 young, healthy, unfamiliar drivers along rural two-lane highways in Ohio under low-beam illumination conditions at night for the approach to a curve/turn warning sign (curve/turn symbol) for two selected curves. The first-look distance (longitudinal distance measured from the sign to a driver's eyes at which a driver foveally fixates the sign for the first time), last-look distance (the distance measured from the sign to a driver's eyes where he or she moves the eyes away from the sign for the last time before reaching the sign), number of looks, and durations of looks at the warning sign were of main interest in this study. Cumulative last-look distance, first-look duration, and last-look duration graphs were established. The results of this study and a previous similar study indicate that drivers look on average about two times at a warning sign during a nighttime low-beam approach. The author found that between the first look (information acquisition) and the last look (confirmation) at a sign there was usually at least one eye fixation on the roadway ahead.

Using cumulative eye fixation duration data obtained for straight-road driving under low-beam nighttime conditions published in another study and an average saccade duration of about 0.03 seconds, a sign-reading distance model was developed that determines the distance (minimum required legibility distance (MRLD)) at which a simple bold symbol on a warning sign must be recognized. The model provides for a given speed the overall cumulative probability distribution function for the MRLD in terms of distance or in terms of time. The advantage of this model, which is applicable to warning signs with simple symbols under low-beam illumination at night, is that it is totally based on observed, recorded, and analyzed driver eye-scanning and information-seeking behavior in the field.

REFERENCE RESULTS: COUNTERMEASURES

Reducing crash fatalities on rural roadways: Estimating impacts of legislation-based safety improvement measures

Author(s): Knapp, Keith[1]
Year: 2011
Source: Transportation Research Record, no. 2213, pp. 29–36
Publisher: Transportation Research Board
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Many factors that contribute to fatal crashes are related to human behavior. One way to adjust these behaviors is to enact and enforce legislation-based safety improvement measures (LSIMs). The author's objective was to investigate the feasibility and application of a research-based rural safety policy improvement index (RSPII) framework that could be used to quantify the State-by-State impacts of LSIMs on crash fatalities on rural roadways. During this project, NCHRP Report 622 was published. It categorized 23 behavioral highway safety countermeasures as proven with high-quality research. A review of the research and NCHRP Report 622 showed that an RSPII was feasible. A six-step RSPII framework was developed, and six LSIMs were selected for further consideration: primary enforcement of seat belt use, universal motorcycle helmet use, regular application of sobriety checkpoints, graduated driver-licensing program upgrades, mandatory ignition interlock installation, and automated speed enforcement. The author completed a State-by-State estimate (based on current research) of how enactment and proper implementation and enforcement of these LSIMs could reduce crash fatalities on rural roadways. The national fatality reductions estimated for each LSIM ranged from 120 to 699. The author describes the RSPII feasibility investigation, summarizes the six-step RSPII framework, presents the national results from the framework application, discusses the challenges related to the framework application, and gives recommendations for using and improving the RSPII framework.

Driving simulators for robust comparisons: A case study evaluating road safety engineering treatments

Author(s): Jamson, Samantha;[1] Lai, Frank;[1] Jamson, Hamish[1]
Year: 2010
Source: Accident Analysis and Prevention, vol. 42, no. 3, pp. 961–971
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Road authorities considering the implementation of speed management interventions should have access to the results of scientifically robust evaluations on which to base their decisions; however, studies that evaluate a diverse range of interventions with comparable metrics are rare, with most focusing on one type, for example, types of signage, perceptual countermeasures, or physical traffic calming. The authors describe a driving simulator study designed to overcome these constraints. The authors developed twenty diverse speed-reducing treatments and tested them in urban and rural road environments. Forty participants encountered all the treatments, allowing comparisons to be made regarding their driving behavior when the treatment was not present. A number of speed parameters were developed to encapsulate the range of effects of the treatments. The results suggest that although straight sections of road are difficult to treat, speed reductions can be obtained by increasing risk perception. In contrast, alerting treatments had more effect at junctions, particularly in an urban environment: Drivers approaching curves demonstrated improved speed adaptation if the curve radius was highlighted (either implicitly or explicitly). The study highlights how driving simulators can be used to overcome methodological constraints encountered in real-world evaluations of this type.

Predicting single-vehicle fatal crashes for two-lane rural highways in the southeastern United States

Author(s): Zhu, Hong;[1] Dixon, Karen K.;[1] Washington, Simon;[2] Jared, David M.[3]
Year: 2010
Source: Transportation Research Record, no. 2147, pp. 88–96
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The rural two-lane highway in the southeastern United States is frequently associated with a disproportionate number of serious and fatal crashes and as such remains a focus of considerable safety research. The Georgia Department of Transportation spearheaded a regional fatal crash analysis to identify various safety performances of two-lane rural highways and to offer guidance for identifying suitable countermeasures with which to mitigate fatal crashes. The fatal crash data used in this study were compiled from Alabama, Georgia, Mississippi, and South Carolina. The database, developed for an earlier study, included 557 randomly selected fatal crashes during 1997 or 1998 or both (this varied by

State). Each participating State identified the candidate crashes and performed physical or video site visits to construct crash databases with enhanced site-specific information. Motivated by the hypothesis that single- and multiple-vehicle crashes arise from fundamentally different circumstances, the research team applied binary logit models to predict the probability that a fatal crash is a single-vehicle run-off-road fatal crash given roadway design characteristics, roadside environment features, and traffic conditions proximal to the crash site. A wide variety of factors appears to influence or be associated with single-vehicle fatal crashes. In a model transferability assessment, the authors determined that lane width, horizontal curvature, and ambient lighting are the only three significant variables that are consistent for single-vehicle run-off-road crashes for all study locations.

Cost-effective safety improvements for two-lane rural roads

Author(s): Wang, Yinhai;[1] Nguyen, Ngan Ha;[1] Levy, Atli;[1] Wu, Yao-Jan[1]
Year: 2008
Source: Final Technical Report TNW2008-04, Research Project Agreement No. 61-2394
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Traffic accidents cause loss of life and property. Proper identification of accident causal factors is essential for composing countermeasures against traffic accidents and reducing related costs; however, two-lane rural roads have distinctive roadway characteristics compared with other types of roads. To find cost-effective countermeasures and prioritize roadway safety improvement plans for two-lane rural roadways, a better understanding of the relationship between accident risk and respective characteristics is necessary. The authors focused on accident analysis of two-lane rural roads in Washington State. Six representative State routes (SRs)—SR-2, SR-12, SR-20, SR-21, SR-97, and SR-101—were selected as study routes based on their location, length, and geometric characteristics. Along with the 6-year (1999–2004) accident data from the Highway Safety Information System (HSIS), the authors used roadway video image data and geographical information system data retrieved from the Washington State Department of Transportation in this study. The authors used econometric modeling methods to identify accident causal factors and to evaluate their impacts on accident risk at roadway segments and intersections, respectively. Results from the statistical analyses and accident risk models not only help identify accident causal factors, but also provide valuable insights for developing countermeasures against two-lane rural road traffic accidents.

Analysis of nighttime driver behavior and pavement marking effects using fuzzy inference system

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Year: 2007
Source: Journal of Computing in Civil Engineering, vol. 21, no. 3, pp. 200–210
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Nighttime driving behavior differs from that during the day because of differences in the driver's field of view. At night, drivers must rely on their vehicle headlights to illuminate the roadway. It is essential then that the roadway delineation system provides the appropriate lane guidance to motorists when navigating a roadway, particularly one that is curvilinear. The authors conducted a nighttime driving experiment to collect user-perception data of various pavement markings and markers applied to horizontal curves. The effectiveness of each pavement marking was rated by using a subjective scale. A fuzzy inference system was used to analyze the subjective pavement marking and marker evaluation ratings provided by the research participants. Pavement marking effectiveness, horizontal curve sharpness, and driver age were used to develop a fuzzy index for nighttime driving condition (FIND). Based on the FIND, the results indicate that drivers prefer for a combination of treatments to be applied to horizontal curves rather than only a single treatment. A bright centerline, bright edge line, and bright retro-reflective–raised pavement marker combination treatment, and a bright centerline and bright edge line combination treatment, resulted in the highest FIND score. A bright, 8-inch (20.3 cm) edge line, applied alone to a horizontal curve, scored the lowest FIND.

The role of visual and nonvisual feedback in a vehicle steering task

Author(s): Wallis, Guy;[1] Chatziastros, Astros;[2] Tresilian, James;[1] Tomasevic, Nebojsa[3]
Year: 2006
Source: Journal of Experimental Psychology: Human Perception and Performance, vol. 33, no. 5
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The authors report on a study of drivers' vehicle steering, focusing on the task of lane-changing and the role of different sources of sensory feedback. Participants completed two experiments in a fully instrumented, motion-based simulator. Despite the high level of realism created by the simulator, participants were unable to complete lane changes in the absence of visual feedback. When asked to produce the steering movements required to change lanes and turn a corner, participants produced remarkably similar behavior in each case, revealing a lack of understanding of how a lane-change maneuver is normally executed. Participants were then asked to change lanes in a fixed-based simulator, in the presence of intermittent visual information. Normal steering behavior was restored using brief but suitably timed exposure to visual information. The authors conclude that vehicle

steering control can be characterized as a series of unidirectional, open-loop steering movements, each punctuated by a brief visual update.

Low-cost local road safety solutions

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For the past decade or more, the majority of motor vehicle fatalities in the United States has occurred on two-lane rural roads. In December 2005, the National Highway Traffic Safety Administration released a new report, *Contrasting Rural and Urban Fatal Crashes 1994–2003*. That report noted that between 1994 and 2003 there were 372,738 fatal crashes on U.S. roadways. Of those, some 218,539, or 58.6 percent, occurred on rural roads. During the same period, the rural fatality rate was 2.4 per 100 million vehicle mile traveled. The corresponding urban fatality rate is 1.0.

Segment characteristics and severity of head-on crashes on two-lane rural highways in Maine

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Year: 2006
Source: Accident Analysis and Prevention, vol. 38, no. 4, pp. 652–661
Publisher: Elsevier
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More than two out of three of all fatal crashes in Maine occur on rural, two-lane collector or arterial roads. Head-on crashes on these roads account for less than 5 percent of the crashes, but they are responsible for almost half of all fatalities. Data analyzed in this study were provided by the Maine Department of Transportation and cover all head-on crashes for 2000–2002, during which period there were 3,136 head-on crashes reported. Out of these, 127 were fatal crashes and 235 produced incapacitating but not fatal injuries. These two categories made up over 75 percent of the crash cost. A clear majority of head-on crashes on two-lane, rural roads in Maine were caused by drivers making errors or misjudging situations. Illegal/unsafe speed was a factor in 32 percent of the crashes whereas driver inattention/distraction was a primary factor in 28 percent. Fatigue was responsible for around 1 in 40 crashes and 1 in 12 fatal crashes. Alcohol or drugs was a factor in 1 in 12 crashes and 1 in 9 fatal head-on crashes. Less than 8 percent of fatalities involved someone overtaking another vehicle, and only around 14 percent involved a driver intentionally crossing the centerline. Two in three fatal head-on crashes occurred on straight segments, and 67 percent of these happened on dry pavement. There is a clear trend toward higher speed limits leading to a higher percentage of crashes becoming fatal or having incapacitating injuries. There is also a clear trend—if one keeps speeds constant and annual average daily traffic within a certain range—that wide shoulders lend to higher crash severities. In addition, for higher speed roads, more travel lanes (more than two) increase crash severity. In summary, there seem to be two major reasons why people get across the centerline and have head-on collisions: (a) People are going too fast for the

roadway conditions or (b) people are inattentive and get across the centerline more or less without noticing it. The latter category of crashes could probably be reduced if centerline rumble strips were installed. More or less of all head-on collisions could be eliminated if median barriers were installed. In-vehicle technology could also be used to significantly reduce the incidence of lane departures. Furthermore, today's speed limits should be better enforced, because a high percentage of serious crashes involve illegal speeding. This should be combined with lowered speed limits for targeted high-crash segments.

Driver visual search of objects in and near the roadway

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Highway systems require roads, traffic control, and users. To assure safety, each of these components must function as a combined unit. Too often, highway designers and traffic engineers develop road systems that fail to recognize the needs and limitations of users. Highway designers must know what impact their design decisions will have on road traffic control required by traffic engineers and how that will subsequently affect users attempting to drive efficiently and safely. Traffic engineers cannot be expected to solve design problems with engineering fixes. Road users should have a clear understanding of how to drive on a safe road based on the design and control deployed on the road. The objective of this report is to illustrate a simple, inexpensive procedure that highway designers, traffic engineers, and researchers can use to identify the most significant information drivers use when making driving-task decisions. When using the procedure, it is apparent when traffic control and geometric features compete for road-user attention, for example, when speed limit signs are too close to short vertical sight distance curves. Such user information can then be used jointly by highway designers and traffic engineers to develop guidelines for road features and traffic control systems appropriate for road safety.

Safety impact of edge lines on rural two-lane highways

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Pavement markings are an important part of the traffic control system, especially on rural two-lane roadways where such treatments often are the major traffic control measure. Compared with other types of longitudinal markings, the effect of edge lines on safety and driver behavior has not been well investigated; however, such markings may have a positive impact on the reduction of crashes on two-lane rural roads, as well as on the general comfort level of driving. The authors compiled an inventory of rural two-lane highways under the operation of the Texas Department of Transportation, investigated typical dimensions and characteristics of such roadways, and utilized this information to perform a detailed accident statistical analysis. The authors made crash statistics comparisons for highways with and

without edge lines. In addition to general accident frequency analysis, varying traffic lane and shoulder widths, and roadway curvature, factors such as accident type, intersection presence, light condition, surface condition, crash-supporting factors, severity, driver age, and driver gender were considered. The research showed that edge line treatments on rural two-lane roadways may reduce accident frequency up to 26 percent and the highest safety impacts occur on curved segments of roadways with lane widths of 9–10 ft. In addition, edge line presence shows some positive safety impact in reducing speeding-related accidents that occur in darkness that may be related to better driver path and speed perception.

Southeastern United States fatal crash study

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A significant safety issue in the United States is the substantial number of vehicle-related crashes. The number of fatal crashes in the southeastern portion of the United States (i.e., Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee) is disproportionately higher than those for the entire country. In general, these eight southeastern States collectively report approximately 26 percent of the total annual number of fatal automobile-related crashes in the United States. On average, the southeastern States experience an additional 30 fatalities per million vehicle miles traveled than the U.S. average. The Federal Highway Administration and the eight southeastern States initiated a joint research effort for the region to study this observed over-representation of fatal crashes. Findings of the study suggest that improved features, such as widening shoulders, enhancing delineation, and protecting the clear zone, would substantially reduce the number of fatal crashes. Some of the researchers recommended that additional procedures and policies may be an appropriate countermeasure for wide-scale improvements. Countermeasures (physical as well as political) were explicitly recommended to address two-lane rural roads, safety restraint use, and fixed-object crashes. A supplemental finding was the presence of extensive pavement edge drop-offs for fatal crash sites in at least two of the participating States. As this observation occurred as a result of field inspection and was not initially identified as a target problem, it was not studied in great detail for this research effort but merits special comment because it is potentially a significant finding of the study.

Growing traffic in rural America: Safety, mobility, and economic challenges in America's heartland

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This report examines the use, condition, and safety of the non-Interstate rural roads in the United States, based in part on a recent analysis of the totality of fatal rural traffic accidents in the 5-year period from 1999 to 2003. The report also investigates the measures some States are undertaking to improve traffic safety on rural roads and ends with recommendations for reducing traffic fatalities on rural roads in the United States.

Modeling driver visual demand on complex horizontal alignments

Author(s): Easa, Said;[1] Ganguly, Chandi[1]
Year: 2005
Source: Journal of Transportation Engineering, vol. 131, no. 8, pp. 583–590
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Visual information is one of the vital elements that affect driver workload. Previous studies have modeled driver visual demand on simple horizontal curves and have found that it is significantly affected by the curve radius. The authors modeled driver visual demand on complex horizontal alignments that may have included simple, compound, and reverse curves. Two sets of visual demand models were developed (curve models and tangent models) using visual demand data collected on 18 highway alignments on a driving simulator. The results show that visual demand is affected by the characteristics of not only the current element but also the preceding element. The characteristics of the preceding element included curve radius, curve direction (right or left), deflection angle, and lane width. As such, the developed models represent important tools for accurately evaluating driver workload on complex horizontal alignments.

How much visual road information is needed to drive safely and comfortably?

Author(s): De Waard, Dick;[1] Steyvers, Frank J.J.M.;[1] Brookhuis, Karel A.[1]
Year: 2004
Source: Safety Science, vol. 42, no. 7, pp. 639–655
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   http://www.rug.nl/corporate/index?lang=en

The authors used an advanced driving simulator to explore the questions "How much visual information from the road is required for proper driving?" and "How do people cope with a visually ambiguous road configuration?" Sixteen young and 16 elderly drivers completed two test rides on a rural road that was divided into five sections of 2 km. At each section, a road element (e.g., delineation, roadside marker) was added or removed. During the rides, performance (e.g., lateral position, speed), and heart rate were recorded continuously, and before transition to a new section, drivers gave a rating on invested effort and on visibility of the (previous) road course. The authors' goal was to determine whether a shift in driving behavior could be noticed at a certain amount of visual information. The main threshold found—for both age groups—lies between roads with "no delineation on the road surface at all" and "a center line." Elderly drivers, however, appeared to need the visual aid of the center line to a greater extent than did young drivers, and in general they drove slower and regulated their information input in this way. A visually ambiguous road situation concluded the experiment. The participants drove on a center-lined road toward a junction where the road forked to the left and right. The left-hand road was a road without delineation but with lampposts, and the right-hand road was a continuation of the center-lined road without lampposts. In particular, elderly drivers were confused by this situation and chose the road with lampposts more often.

This finding supports the assumption that with increasing age, people are more easily confused by ambiguous cues.

Treatments for crashes on rural two-lane highways in Texas

Author(s): Fitzpatrick, Kay;[1] Parham, Angelia H.;[1] Brewer, Marcus A.[1]
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Most of the crashes in rural areas occur away from intersections and driveways (60 percent), whereas most urban crashes occur at or are related to either intersections or driveways (57 percent). The distribution of crashes by first harmful event also clearly shows an urban versus rural division. In urban areas, most of the crashes involve another vehicle (81 percent), whereas only about half in the rural area involve another vehicle (51 percent). Striking a fixed object is more common in rural areas (25 percent) than in urban areas (14 percent). The authors provide transportation practitioners with information on crash characteristics for rural roads in Texas. They also present discussion on low-cost safety treatments used on highways and at intersections along with their known effectiveness. Treatments discussed for highways include rumble strips, passing improvements, two-way left-turn lanes, lane or shoulder widening, pavement edge drop-off improvements, pavement markings, mowing, skid-resistance improvements, side slope flattening, recovery distance improvements, tree mitigation, culvert modifications, advance warning for horizontal curves, delineation, barrier reflectors, and animal countermeasures. Treatments discussed for intersections include advance warning for intersections, approach rumble strips, left-turn bays, shoulder bypass lanes, intersection flashing beacons, signalization, high-intensity strobe lights, and backplates on traffic signals, illumination, and sight obstruction reduction. Experiences with selected treatments in Texas, including whether the treatment would be considered elsewhere, are also included in the report.

Safety impacts of rural road construction

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Crash data in Kentucky show that the fatal crash rate on two-lane rural roads is substantially higher than on any other type of road. Improvements have been proposed at some locations on this type of road, which involve either upgrading the existing two-lane road or adding lanes resulting in a four-lane road. As part of the public information process, highway officials were asked to document the previous results of this type of construction. The objectives of this study were to (1) identify sections of two-lane rural roadways where either the two-lane road had been realigned and reconstructed or additional lanes had been added and (2) conduct a before-and-after analysis to determine how these changes affected traffic crashes. Of the 49 locations included in the study, 25 involved adding lanes and converting to a four-lane road, whereas the two-lane road was upgraded (realignment with wider lanes and shoulders) at 24 locations. Before construction, the average traffic volume was almost three times higher on the roads where additional lanes

were added than where the two-lane road was upgraded. The average daily traffic increased dramatically after construction was completed, with a slightly higher increase for roads where lanes were added. When all the locations are considered, there was a 51-percent reduction in the crash rate when the road was upgraded and a 56-percent reduction in the crash rate when lanes were added. The rate was reduced from 250 to 122 crashes/100 million vehicle miles (MVM) when the road was upgraded and from 258 to 114 crashes/100 MVM when lanes were added. When only the number of crashes is considered, the number of crashes per mile decreased by 39 percent when the road was upgraded and by 45 percent when lanes were added. The rate of injury or fatal crashes was reduced by 54 percent for upgrading the road and 55 percent by adding lanes, whereas the number of crashes per mile decreased by 43 percent both when the road was upgraded and when lanes were added. The overall conclusion of the study is that both upgrading two-lane rural roads and converting the road to four lanes are effective methods of reducing total crashes and injury or fatal crashes. The traffic volume would determine the appropriate alternative.

Effects of traffic control devices and road scenes on a driver's judgment on curve sharpness

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Year: 2001
Source: Driving Assessment 2001: The First International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design
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The authors conducted field experiments on a 12-km section of rural highway running through a hilly area in Hokkaido to study the effects of traffic control devices and road scene on a driver's judgment of curve sharpness. The authors obtained configurations of traffic control devices at 36 curves from the road maintenance database. The authors subjectively determined the favorability of the road scene. Each of the six subjects drove a vehicle installed with instruments. The subject estimated the sharpness of the target curve before that curve and assessed the accuracy of that judgment subjectively after the target curve. Cluster analysis detected groupings of the 36 curves in terms of driver assessment of sharpness. The traffic control devices were verified as important cues in driver assessment of curve sharpness. In addition, the road scene had a positive effect in daytime on judgment of the target curve; however, there were some dangerous curves where the subjects underestimated the sharpness before entering the curve. Traffic control devices to provide accurate information on curve depth should be developed.

Effects of horizontal curvature on driver visual demand

Author(s): Wooldridge, Mark D.;[1] Fitzpatrick, Kay;[1] Koppa, Rodger;[1] Bauer, Karin[1]
Year: 2000
Source: Transportation Research Record, no. 1737, pp. 71–77
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    United States, http://tti.tamu.edu/

A consistent design allows drivers to perform safely the task of driving, allowing attention or capacity to be dedicated to obstacle avoidance and navigation. A measure of the consistency of a design is the amount of visual information needed by a driver to maintain an acceptable path on the roadway. Vision occlusion is a technique that measures driver visual demand on a roadway. It allows a more direct evaluation of the effects of various geometric elements on the driver. Studies of the effects of variations of curve radius, deflection angle, spacing, and sequences revealed several relationships between roadway geometry and visual demand. Curve radius and its reciprocal were found to be significantly related to visual demand in both on-road and test track studies. Small changes in visual demand were also found between types of curve pairs (S and broken back) with differing spacing between the curves. Visual demand was found to be a promising measure of effectiveness for use in studies of design consistency.

An operational and safety evaluation of alternative horizontal curve design approaches on rural two-lane highways

Authors: Voigt, Anthony P;[1] Krammes, Raymond A.[1]
Year: 1998
Source: Transportation Research Circular
Publisher: Transportation Research Board
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This paper evaluates the effects of super-elevation on 85th percentile speeds and accident experience as well as the effects of side friction demand on accident experience at horizontal curves on rural two-lane highways. These evaluations were conducted as part of research toward development of a design consistency evaluation model for the United States. The operating speed analysis verified previous models that used degree of curvature, length of curve, and deflection angle as independent variables for estimating 85th percentile speed on curves. The analysis also found super-elevation to be a statistically significant independent variable. Independent variables in the accident analysis included degree of curvature, operating speed reduction, super-elevation deficiency, and implied side friction demand. Operating speed reduction and super-elevation deficiency were found to be significant accident predictors; however, implied side friction demand was the strongest accident surrogate. Comparisons of alternative horizontal curve design methods, with respect to which speed should be used for the design of curves, were made. The 85th percentile speed on a curve was the strongest performer of four curve design ideologies and is recommended for use in horizontal curve design. Super-elevation has significant effects on 85th percentile speed on rural two-lane horizontal curves. Operating speed reduction, super-elevation deficiency and side friction demand based on 85th percentile

operating speeds have significant effects on the safety of horizontal curves. These findings provide further support of the adoption of an operating-speed–based design procedure for two-lane rural highways in the United States.

Use of pavement markings to reduce excessive traffic speeds on hazardous curves

Author(s): Retting, Richard A.;[1] Farmer, Charles M.[2]
Year: 1998
Source: ITE Journal, vol. 68, no. 9, pp. 30–36
Publisher: Institute of Transportation Engineers
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The authors report on a research experiment that examined the effectiveness of special pavement markings intended to reduce excessive traffic speeds at rural and suburban two-lane roadway locations with sharp horizontal curvatures. The experiment was conducted at a single location on a suburban two-lane secondary road in northern Virginia that includes a sharp left curve—approximately 90 degrees (1.6 rad)—preceded by a long tangent section. An advisory speed of 15 mi/h (24 km/h) is posted approximately 500 ft (152 m) before the curve using a standard reverse-turn sign and advisory speed plate. The experimental pavement marking was intended to reinforce this existing advisory and consisted of the word "SLOW" in 8-ft–high (2.4 m) white letters, a white 8-ft–high (2.4 m) left-curve arrow, and an 18-inch–wide (46 cm) white line perpendicular to the road at both the beginning and end of the text/symbol message. A separate left curve—approximately 45 degrees (0.8 rad)—in the opposite direction of the same highway, approximately one-quarter mi (0.4 km) away, was chosen as a control site. At the experimental site, traffic speeds were measured on the tangent section 90 ft (27 m) prior to the point of curvature before and after installation of the pavement marking. At the upstream site, traffic speeds were measured to approximately 650 ft (198 m) prior to the point of curvature. At the experimental site, the mean traffic speed dropped from 34.3 mi/h (55.2 km/h) during the baseline to 33.2 mi/h (53.4 km/h) after marking. In contrast, speeds increased at both the upstream and control sites. The percentage of vehicles exceeding 40 mi/h (64 km/h) on the experimental curve dropped by more than half, from 9.1 percent to 3.5 percent.

Curve radius perception accuracy as a function of number of delineation devices (chevrons)

Author(s): Zwahlen, Helmut T.;[1] Jin, Young Park[1]
Year: 1995
Source: Transportation Research Record, no. 1495, pp. 99–106
Publisher: Transportation Research Board
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The authors investigated monocular and binocular curve radius perception accuracy of 10 young drivers under curve approach and nighttime conditions using a 1:50 scaled

laboratory setup. The experiment consisted of a sequential comparison of a 90-degree segment of a right curve with a standard radius equipped with 12 equally spaced 1:50 scaled retroreflective yellow and black miniature chevron signs with a 90-degree segment of a test curve (right curve), which could have either two, three, four, or eight equally spaced 1:50 scaled retroreflective miniature chevron signs along a curve radius of either 95, 97.5, 100, 102.5, or 105 percent of the standard curve radius. For each experimental presentation the standard curve was presented first to the subjects (black road environment and chevrons illuminated by electrically controlled headlamps) for 2 seconds, then the subjects rotated 90 degrees and were presented with the test curve (one of five curve radii, with either two, three, four, or eight equally spaced chevrons) for 2 seconds. A forced-choice response (smaller or larger than the standard curve radius) was required from the subjects. All experimental conditions (five radii, four chevron levels, five replications for each subject) were randomized within a viewing condition for each subject. The curve-approach viewing distance from the subject's eyes to the beginning of the 90-degree segment of the curve was 4.57 m, which represents 228.6 m in the real world, whereas the curve radius of the standard curve was 0.914 m, which represents a curve radius of 45.6 m (38-degree curvature) in the real world. All chevrons were within a total visual field of view of about 11 degrees. The overall averages for the percentage of the number of correct responses were calculated for the two-, three-, four-, and eight-chevron conditions for each radius of the test curve for binocular viewing and monocular viewing, and these percentages were plotted against the number of chevrons. The average of the correct responses for the five test-curve radii increases for the binocular viewing conditions from 56 percent for two chevrons, to 62.5 percent for three chevrons, to 82.5 percent for four chevrons, and remains about the same (81.0 percent) for eight chevrons. For monocular viewing, the average correct responses increase from 50 percent for two chevrons, to 64 percent for three chevrons, to 70.5 percent for four chevrons, and remains about the same (72.5 percent) for eight chevrons. Overall, for the five test-curve radii and for the four chevron levels, the binocular viewing condition (especially for four and eight chevrons) produces a somewhat higher overall average value for correct responses (70.6 percent binocular versus 64.3 percent monocular). On the basis of analysis of variance, the curve radii, the number of chevrons, and the viewing conditions are statistically all highly significant factors (0.05 level, interactions not significant). Considering the monocular results as more applicable for the real-world curve approach, the authors concluded that, for the conditions investigated in this study, four equally spaced chevrons within a total visual field of about 11 degrees provide adequate curve-radius–estimation cues for drivers as they approach an unfamiliar curve at night.

REFERENCE RESULTS: COMPUTER VISION/MACHINE VISION

Road curvature estimation for vehicle–lane–departure detection using a robust Takagi–Sugeno fuzzy observer

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Year: 2013
Source: Vehicle System Dynamics, vol. 51, no. 5, pp. 581–599
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In this paper, the authors studied and evaluated a lane-departure–detection method via professional vehicle dynamics software. On the basis of a robust fuzzy observer designed with nonmeasurable premise variables with unknown inputs, the road curvature was estimated and compared with the vehicle trajectory curvature. The difference between the two curvatures was used by the proposed algorithm as the first driving risk indicator. To reduce false alarms and take into account the driver corrections, a second driving risk indicator was considered, which was based on the steering dynamics, and it gives the time to the lane-keeping. The used nonlinear model deduced from the vehicle lateral dynamics and a vision system is represented by an uncertain Takagi–Sugeno fuzzy model. Taking into account the unmeasured variables, an unknown input fuzzy observer was then proposed. Synthesis conditions of the proposed fuzzy observer were formulated in terms of linear matrix inequalities by using the Lyapunov method. The proposed approach was evaluated under different driving scenarios by using a software simulator. Simulation results show good efficiency of the proposed method.

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Road geometry classification by adaptive shape models

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Vision-based road detection is important for different applications in transportation, such as autonomous driving, vehicle-collision warning, and pedestrian-crossing detection.

Common approaches to road detection are based on low-level road appearance (e.g., color or texture) and neglect of the scene geometry and context; hence, using only low-level features makes these algorithms highly dependent on structured roads, road homogeneity, and lighting conditions. Therefore, the authors sought to classify road geometries for road detection through the analysis of scene composition and temporal coherence. Road geometry classification is proposed by building corresponding models from training images containing prototypical road geometries. The authors propose adaptive shape models where spatial pyramids are steered by the inherent spatial structure of road images. To reduce the influence of lighting variations, invariant features were used. Large-scale experiments showed that the proposed road geometry classifier yields a high recognition rate of 73.57 percent ±13.1, clearly outperforming other state-of-the-art methods. Including road shape information improved road detection results over existing appearance-based methods. Finally, it was shown that invariant features and temporal information provide robustness against disturbing imaging conditions.

Lane tracking and obstacle avoidance for autonomous ground vehicles

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The authors present a comprehensive experimental and theoretical study of a proposed mechatronics system for an autonomous ground vehicle (AGV). This vehicle has the capability of lane detection, tracking, and obstacle avoidance. The system considered uses a computer vision technique in which real time data are collected by a single calibrated camera. Further processing and analysis to the images captured by the camera are carried out to recognize the lane lines and the obstacle dimensions. A proportional–integral–derivative controller is implemented to predict and control the vehicle-heading angle to properly follow the lane and/or avoid obstacles. The numerical simulation is implemented in the MATLAB®/Simulink® environment. This choice adds the possibilities of the inclusion of advanced control strategies and the use of the real-time and image-processing toolboxes. For the purpose of analysis and examination, a realization model car was equipped with the proposed mechatronics system and was used to conduct several field tests. The outcomes from both the field experiments and the computer simulation show a good agreement with each other, which reveals the applicability of the proposed system.

Vision-based curvature model for artificial intelligence in vehicles

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Source: Proceedings—2012 International Conference on Control Engineering and Communication Technology, ICCECT 2012, pp. 245–248
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Most vehicles use a Global Positioning System (GPS) for vehicle autonomous driving. Visual information is essential in artificial intelligence in vehicles and should be an important supplement to the GPS-based system; however, road lanes are often curved, making vision-based detection of smooth and continuous curves a challenging task. Furthermore, commonly used computer vision algorithms, such as edge detectors or Hough transform for line or curvature detection, are not robust in changing lighting conditions. The authors present a vision algorithm designed specifically for detecting and modeling road curvature for human-like active steering control and heading adjustment for artificial intelligence in vehicles. The proposed algorithm has been tested in different road conditions and has shown very good results.

Integrated driver and active steering control for vision-based lane keeping

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Year: 2012
Source: European Journal of Control, vol. 18, no. 5, pp. 473–484
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A nested PID (proportional–integral–derivative) steering control for autonomous vehicles equipped with artificial vision systems is designed so that the driver can override the automatic lane-keeping action and obtain complete control of the vehicle lateral dynamics without any switching strategy. The control input is the steering wheel angle: It is designed on the basis of the yaw rate, which is measured by a gyroscope, and the lateral offset, which is measured by the vision system as the distance between the road centerline and a virtual point at a fixed distance ahead from the vehicle. No lateral acceleration and no lateral speed measurements are required. A proportional–integral active front steering control on the basis of the yaw rate tracking error is designed to compensate for constant disturbances while improving vehicle-steering dynamics and reducing the influence of parameter variations. The yaw rate reference is viewed as the control input in an external control loop: It is designed by using a PID control based on the lateral offset measurements to reject the disturbances on the curvature during autonomous control, that is, when the driver is not exerting any torque on the steering wheel. A third control block is designed to allow the driver to control the vehicle (e.g., lane change for passing purposes or obstacle avoidance), overriding the automatic lane-keeping action while maintaining the advantages of the yaw rate feedback. The authors conducted several simulations on a

standard big sedan CarSim® vehicle model to explore the robustness with respect to nonmodeled effects, such as combined lateral and longitudinal tire forces, pitch and roll, and parameter variations. The simulations showed reduced path-following errors and new stable maneuvers in comparison with the model predictive-steering controller implemented by CarSim in both cases of autonomous and nonautonomous control.

Steering control strategy guide by two preview vision cues

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Year: 2012
Source: Science China Technological Sciences, vol. 55, no. 9, pp. 2662–2670
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Vision cues play an important role in states feedback in motion control; however, the existing driver steering models consider little about vision cues utilized by human drivers during their steering procedure. The authors present a novel steering control strategy based on two preview points (far point and near point). The far point is used to compensate the steering wheel by predicting the upcoming curvature change with respect to the lane, whereas the near point is used as vision feedback, which is used to tune the steering wheel by estimating the errors of vehicle states and lane center. To obtain much smoother lateral acceleration during steering, a forward internal model is established by using a second-order yaw dynamics system that captures the influence of yaw angular acceleration caused by the steering wheel angle. The input parameter of the second-order system is the vision cues of both the near and far points, and the output parameters are the ideal yaw angle and yaw rate. To calculate the suitable steering wheel angle, an adaptive controller is designed using fuzzy sliding technology, which is used as the input of the vehicle system dynamics. Numerical simulation results show that the proposed method performs better than the existing driver steering models in the case of imitating human drivers' behavior and exhibits excellent adaption to the lane-curvature change.

Computer vision at the Hyundai Autonomous Challenge

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As interest in autonomous vehicles is growing worldwide, and different approaches—based on different perception technologies and concepts—are being followed. The authors expose the importance of the use of vision technology in most of these approaches and present the experience of the SNUCLE autonomous vehicle, which successfully completed the Hyundai Autonomous Challenge in November 2010.

Intelligent vehicle visual navigation system design

Author(s): Wang, He;[1] Zhang, Yunzhou;[1] Yuan, Quan;[1] Wu, Hao[1]
Year: 2010
Source: 2010 International Conference on Machine Vision and Human–Machine Interface, MVHI 2010, pp. 522–525
Publisher: IEEE
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The authors introduce the visual navigation system design of intelligent vehicles and depict in detail the navigation system architecture and hardware modules. To enhance the speed control of intelligent vehicles, the authors propose and apply a new control method based on proportional–integral–derivative (PID) and bang–bang control. To solve the problem of precisely identifying the navigation line under uneven light and realizing autonomous navigation of the intelligent vehicle, the authors propose a new method of dynamic threshold and provide information on implementation. To enhance the perspective of visual crawling, the system applies a charge-coupled device (CCD) camera to collect path information. Image transformation is adopted to filter incorrect navigation information. Laboratory experiments have proven the stability and accuracy of the entire system.

Looking-in and looking-out of a vehicle: Computer-vision–based enhanced vehicle safety

Author(s): Trivedi, Mohan Manubhai;[1] Gandhi, Tarak;[1,2] McCall, Joel;[1,3]
Year: 2007
Source: IEEE Transactions on Intelligent Transportation Systems, vol. 8, no. 1, pp. 108–120
Publisher: IEEE
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The authors present investigations into the role of computer-vision technology in developing safer automobiles. The authors consider vision systems, which can not only look out of the vehicle to detect and track roads and avoid hitting obstacles or pedestrians, but also can simultaneously look inside the vehicle to monitor the attentiveness of the driver and even predict his or her intentions. In this paper, the authors present a systems-oriented framework for developing computer-vision technology for safer automobiles. The authors consider three main components of the system: environment, vehicle, and driver. The authors discuss various issues and ideas for developing models for these main components, as well as activities associated with the complex task of safe driving. This paper includes a discussion of novel sensory systems and algorithms for capturing not only the dynamic surround information of the vehicle, but also the state, intent, and activity patterns of drivers.

Vision for ground vehicles: History and prospects

Author(s): Dickmanns, Ernst D.[1]
Year: 2002
Source: International Journal of Vehicle Autonomous Systems, vol. 1, no. 1, pp. 1–44
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The author provides a review on the last two decades of vision development for ground vehicles. The line of development for road vehicles based on digital microprocessors dates back to the early 1980s. The European EUREKA project PROMETHEUS (PROgraMme for a European Traffic of Highest Efficiency and Unprecedented Safety) brought about a boost in efforts in this field, with demonstrations in public traffic in 1994 (i.e., Autoroute A1, near Paris). Progress has been and will be governed in the near future by the increase in microprocessor performance by about one order of magnitude every 4–5 years. All basic perception and action tasks for driving have been demonstrated to be performable autonomously. First products are being introduced into the market right now. On the research frontier, the first highly integrated dynamic vision system has become recently operational and is discussed as a reference for future developments (i.e., expectation-based, multifocal, saccadic vision (EMS-Vision) system). Initially, assistance systems will dominate in accumulating experience, whereas the human operator will carry all the responsibility. In the long run, phases of fully autonomous driving may become affordable after clarification of the legal implications. The driver will have a choice as to whether to make use of these capabilities—manual driving is likely to remain an option for the driver so as to enjoy his or her own skills—however, the autonomous system may intervene to prevent accidents from occurring in clearly dangerous situations.

Computer vision and highway automation

Author(s): Dickmanns, Ernst D.[1]
Year: 1999
Source: Vehicle System Dynamics, vol. 31, no. 5, pp. 325–343
Publisher: Taylor and Francis Ltd.
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The author conducted a survey on the development of machine vision for road vehicle guidance. Through early work in real-time simulation with real hardware in the loop at Universität der Bundeswehr München (UBM), and through the EUREKA project PROMETHEUS from 1987 to 1994 following the 100th anniversary of road vehicle developments since 1886, Europe has pioneered the field. Since the first fully autonomous test drives in 1986 and the first participation in public traffic in 1992, considerable progress has been achieved. With continuous growth in the computing power of microprocessors at a rate of about one order of magnitude every 4–5 years, sufficient performance levels for dynamic machine vision will be available within one or two decades. The author discusses the principles of dynamic vision as developed at UBM and performance levels achieved.

Full article can be accessed at http://www.tandfonline.com/doi/abs/10.1076/vesd.31.5.325.8359?tab=permissions#tabModule

Machine-vision systems for intelligent transportation systems

Author(s): Masaki, Ichiro[1]
Year: 1998
Source: IEEE Intelligent Systems and Their Applications, vol. 13, no. 6, pp. 24–31
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The author discusses how intelligent transportation systems can use machine vision to detect lane markings, vehicles, pedestrians, road signs, traffic conditions, traffic incidents, and even driver drowsiness. Challenges of machine-vision systems include making the systems less expensive, more compact, and more robust in various weather and traffic conditions.

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