Lecture Notes in Electrical Engineering 1172

Sanjay Yadav · Yogendra Arya ·
Shailesh M. Pandey · Noredine Gherabi ·
Dimitrios A. Karras *Editors*

Proceedings of 3rd International Conference on Artificial Intelligence, Robotics, and Communication

ICAIRC 2023

Springer

Lecture Notes in Electrical Engineering

Volume 1172

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ISSN 1876-1100 ISSN 1876-1119 (electronic)
Lecture Notes in Electrical Engineering
ISBN 978-981-97-2199-3 ISBN 978-981-97-2200-6 (eBook)
https://doi.org/10.1007/978-981-97-2200-6

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

This book is based on a select collection of contributions from the 2023 3rd International Conference on Artificial Intelligence, Robotics, and Communication (ICAIRC 2023) held on December 22–24, 2023, at Xiamen, China. This book aims to present the essence of the academic conference and explore the importance, significance, and social impact of artificial intelligence, robotics, and communication technologies.

With the rapid development of science and technology, artificial intelligence, robotics, and communication technology are increasingly becoming an indispensable part of our lives. Innovations and advances in these areas have not only changed our daily lives, but have also had a profound impact on society, economy, and culture. This book brings together papers from leading experts and researchers from around the world who have made significant breakthroughs and achievements in cutting-edge explorations in artificial intelligence, robotics, and communication.

The content of this book covers topics on Edge Intelligence, Mobile Robotics, Robot Control, Visual Serving, Information Security, etc. Through rigorous research methods and empirical analysis, these papers demonstrate the wide application of artificial intelligence, robotics, and communication technologies in transportation, medical, industry, and other fields. They reveal the potential of these technologies and their ability to increase productivity, solve social problems, and improve people's quality of life.

We sincerely hope that this book will stimulate readers' interest in artificial intelligence, robotics, and communication technologies and promote exchanges and cooperation between academia and industry. We firmly believe that by sharing knowledge and experience, we can further advance these areas and contribute to building an intelligent, efficient, and sustainable society.

Finally, we would like to thank all the authors and reviewers who contributed to this book. Their efforts and enthusiasm made the publication of this book possible. We hope this book will inspire you and serve as a reference for your exploration in the fields related to artificial intelligence, robotics, and communication.

New Delhi, India — Sanjay Yadav
Faridabad, India — Yogendra Arya
Patna, India — Shailesh M. Pandey
Beni-Mellal, Morocco — Noredine Gherabi
Athens, Greece — Dimitrios A. Karras

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About the Editors

Prof. (Dr.) Sanjay Yadav born in 1962, obtained his master degree in science (M.Sc.) in 1985 and Ph.D. degree in Physics in 1990. He is Former Chief Scientist and Head, Physico Mechanical Metrology Division of NPL, India and Former Faculty of Physical Sciences, Academy of Scientific and Innovative Research (AcSIR), HRDG, Ghaziabad. He taught Advanced Measurement Techniques and Metrology course, took practical classes and supervising graduate, master and Ph.D. students since 2011. He is working as the Editor-in-Chief (EIC) of the *MAPAN: The Journal of Metrology Society of India*. He has significantly contributed to pressure metrology, biomedical instrumentation, ultrasonic transducers and instrumentation systems. His current research interests include research and developmental activities in physico mechanical measurements; establishment, realization, maintenance and up-gradation of national pressure and vacuum standards; dissemination of national practical pressure scale to users through apex level calibration, training and consultancy services; inter-laboratory comparisons, proficiency testing programme and key comparisons, implementation of Quality System in the laboratory as per ISO/IEC 17025 standard and Finite Element Analysis (FEA) and Monte Carlo Simulations for pressure balances. He has over 450 research publications to his credit, published in the national and international journals of repute and conferences besides contributing in several books as editor and author, published by Springer and MSI as well as in drafting several project, scientific and technical reports, documents and policy papers.

Dr. Yogendra Arya is currently working as an Associate Professor with the Department of Electrical Engineering, J. C. Bose University of Science and Technology, YMCA, Faridabad, India. He received his A.M.I.E. in Electrical Engineering from The Institution of Engineers (India), in 2008, M.Tech. (Instrumentation and Control) from DCRUST, Murthal, Haryana in 2010 and a Ph.D. from Delhi Technological University, Delhi in 2018. He has published 60+ research papers in reputed International journals. He has been placed among "Top 2% of Researchers in the World" for 2019, 2020, 2021, and 2022 by Stanford University, USA and Elsevier. He has Google Scholar citations of 3500+ and h-index of 35. He has received "Best Associate Editor Award-2021, 2022, and 2023" from *Journal of Electrical Engineering and*

Technology. He is Associate Editor of a few SCIE journals. He is a regular reviewer of leading journals. He is a Fellow of IETE, SM of IEEE, an Associate Member of The Institution of Engineers (India), and a Life Member of ISTE. His major areas of research interest include instrumentation, control, AGC/LFC in smart grids, fuzzy control, energy storage systems, and renewable energy systems.

Dr. Shailesh M. Pandey's academic journey is rooted in his pursuit of excellence and dedication to his field. He completed his B.Tech. in Mechanical Engineering in the year 2007 and Qualified GATE in 2010. He holds a Master's degree (2012) and a Ph.D. (2017) in Mechanical Engineering from DTU (Delhi Technological University), a prestigious institution known for its strong engineering programs. For his M.Tech. dissertation and Doctoral research work, he had the privilege of being supervised by two esteemed professors, Prof. Qasim Murtaza and Prof. R. S. Walia from Delhi Technological University (DTU) Delhi. Currently, Dr. Pandey serves as a Training and Placement Officer at NIT Patna, where he guides and supports students in their career development, a position he has held since 2020. His area of research includes surface modification, coating, tribology, material processing, composite materials, metal matrix nanocomposites, nano-coatings, wear, deformation, and corrosion. He has guided more than 25 B.Tech. projects and 10 M.Tech. dissertations. At present, 5 Ph.D. Students are working under his supervision. Dr. Pandey is also the founder and president of the educational and skill-development NGO "Avhikalpana" and a Trust "Research and Innovation Trust".

Prof. Dr. Noredine Gherabi is a professor of computer science with industrial and academic experience. He holds a doctorate in computer science. In 2013, he worked as a professor of computer science at Mohamed Ben Abdellah University, and since 2015 has worked as a research professor at Sultan Moulay Slimane University, Morocco. Member of the International Association of Engineers (IAENG). He has several contributions to information systems namely: big data, semantic web, pattern recognition, and intelligent systems. He has papers (book chapters, international journals, and conferences/workshops), and edited books. He has served on executive and technical program committees and as a reviewer of numerous international conferences and journals, he convened and chaired more than 30 conferences and workshops.

Prof. Dr. Dimitrios A. Karras received his Diploma and M.Sc. Degree in Electrical and Electronic Engineering from the National Technical University of Athens (NTUA), Greece in 1985, and a Ph.D. Degree in Electrical Engineering, from the NTUA, Greece in 1995, with honors. From 1990 to 2004 he collaborated as a visiting professor and researcher with several universities and research institutes in Greece. Since 2004, after his election, he has been with the Sterea Hellas Institute of Technology, Automation Department, Greece as an associate professor in Intelligent Systems-Decision Making Systems, Digital Systems, Signal Processing, till 12/2018, as well as with the Hellenic Open University, Department of Informatics as a visiting professor in Communication Systems (the latter since 2002 and up to 2010). Since

1/2019 is an Associate Professor in Intelligent Systems-Decision Making Systems, Digital Systems, and Signal Processing at the National and Kapodistrian University of Athens, Greece, School of Science, Department General as well as Adjunct Associate Professor with the EPOKA university, Computer Engineering Department, Tirana. He has published more than 70 research-refereed journal papers in various areas of intelligent and distributed/multiagent systems, Decision Making, pattern recognition, image/signal processing, and neural networks as well as in bioinformatics and more than 185 research papers in International refereed scientific Conferences. His research interests span the fields of intelligent and distributed systems, Decision Making Systems, multiagent systems, pattern recognition and computational intelligence, image and signal processing and systems, biomedical systems, communications, and networking as well as security. He has served as a program committee member as well as program chair and general chair in several international workshops and conferences.

Artificial Intelligence Control and Information Detection

Generalization Method of Virtual Test Scenarios for Autonomous Vehicles

Zhe Tan, Zhimin Bai, Qiang Yang, and Xiaojuan Li

Abstract Automatic driving is an inevitable development trend in the traffic field. However, unlike traditional driving modes, lots of simulation test scenarios for autonomous vehicles are required before the operation in real environment to ensure the safety during the actual operation. At present, the actual environment testing method has high cost and low efficiency and cannot test a large number of test scenarios within a certain time period. Therefore, the paper mainly studies the generalization method of virtual test cases for autonomous vehicles. The test scenarios are divided into three types: functional scenario, logical scenario, and concrete scenario. The main indicators of the actual test environment and their hierarchical relationship are analyzed, and the indicator hierarchical model is established. Based on the hierarchical relationship of different indicators and multi-tree building method, the paper studies the generalization method of functional scenarios. Then, the distribution functions and values' range of parameters are obtained by extracting and analyzing the quantifiable parameters of function scenario, and the logical scenarios are obtained. Within the range of different indicators, the selection method of specific values is studied. By analyzing the spatial relationship between different parameters, the combination method between these parameters is determined, and the concrete scenarios that can be used in actual test cases are obtained. Finally, the feasibility of the proposed method is verified by a case study.

1 Introduction

The virtual simulation test of the scenario is important for autonomous vehicles. Before the autonomous vehicles operate in the real traffic environment, the test and evaluation for the security of the autonomous vehicles is critical. Nowadays,

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S. Yadav et al. (eds.), *Proceedings of 3rd International Conference on Artificial Intelligence, Robotics, and Communication*, Lecture Notes in Electrical Engineering 1172, https://doi.org/10.1007/978-981-97-2200-6_1

automated or semi-automated automobile testing lines are widely used in many mass-produced automobile factories. And this will inevitably generate a lot of costs and uncertainty. Therefore, the paper proposes a generation method of virtual scenarios for autonomous vehicles.

The PEGASUS project developed a verification framework for the issuance process of autonomous vehicles. Pütz [1] introduced the database entity and procedure of the PEGASUS project. Staplin [2] developed a test scenario framework that incorporates elements of each operational components. The framework used a checklist-type approach to identify high-level scenario tests by specifying relevant tactical maneuvers. Zhou [3] elaborated and compared the latest developments of five simulation test methods for autonomous vehicles in order to test and verify the rationality and stability of algorithms and system more efficiently. Menzel [4] divided the scenarios into three categories: functional scenarios, logical scenarios, and concrete scenarios, and introduced the conversion relationship among these three types of scenarios. Wang [5] proposed a test scenario generation system and method for the autonomous vehicles. This system included some function modules such as test content generation module, test scenario base, test scenario layout module, and test route generation module. Xia [6] provided a method to generate more effective and compact test scenarios for intelligent driving systems. An index is firstly proposed to measure the complexity of scenario by AHP method. And the complicated cases are preferred to be clustered together into continuous scenarios. Ni [7] proposed an improved deep network-based scene classification method. An improved faster region with convolutional neural network features (RCNN) network is used to extract the features of representative objects in the scene. Zhu [8] proposed that the test scenario for autonomous vehicles is a combination between the driving environment and the driving situation. By analyzing virtual technology of scenarios for autonomous vehicles, the test scenarios were built based on the elements data collection. Shu [9] screened out basic test scenario groups which could cover various levels and functions of the real driving environment by determining complex scenario groups and selecting parameter combination criterion. Wei [10] combined two methods, traffic data-driven basic scene construction and mechanism and theory-based logical scenario construction, to obtain a basic scenario composed of several traffic accident feature variables. The other traffic participants combine their movement directions around the main vehicle in the basic scenario, in order to generalize more logical scenarios. Zhang [11] proposed a road testing scenario for L3-level autonomous driving highways based on the application scenarios of L3-level autonomous driving highways, including emergency response of autonomous driving vehicles, human intervention capabilities, and comprehensive driving capabilities and testing items.

The paper studies the generalization method of simulation test scenarios for autonomous vehicles. Through the abstraction of the actual scenario, the relevant indicators of the test scenario are established, and the hierarchical relationship between the indicators is analyzed. In this paper, the scenarios are divided into three levels according to the demand which are functional scenario, logical scenario, and concrete scenario. And the generation method for these different scenarios is studied.

The functional scenario is a structured informal description. The data of functional scenario is analyzed and clustered through the actual road conditions. Based on functional scenarios, the parameters' distribution and space of each scenario are analyzed, and the logical scenarios are obtained. Then, based on the logical scenarios, the specific value selection method is studied by the parameter distribution function. And the concrete scenario can be obtained by selecting and reorganizing the discrete parameter values.

2 Indicators Hierarchical Model

Each virtual test scenario has different parameters, mainly including road geometric parameters, traffic flow parameters, environmental parameters, and autonomous vehicle parameters. The paper determines the hierarchical relationship of these parameters for generating different test scenario. The indicators of each level for the different test scenario are shown in Table 1. According to the indicators hierarchical model, the tree model can be built for generating different test scenario. By searching the sequence of the multi-tree parameters, the different functional scenarios can be obtained. For the same level, the different scenarios are generated simultaneously, such as four different scenarios can be obtained in Level 3. For the different levels, the indicators can be added in the scenarios generated by the upper level, and the new scenarios can be obtained.

3 Functional Scenario Construction

The function scenarios can be generated as follows.

1. The basic scenarios are generated by Levels 1–4 for different road conditions. And the different conditions of traffic signs and lines are added to Level 5.
2. Based on the scenarios of different road conditions, the indicators of traffic flow are added to Levels 6–8. The position relationship between the two vehicles (test vehicle and the surrounding vehicle) can be confirmed by the position relationship matrix. Then the different behaviors of the surrounding vehicles are added to generate the different scenarios. Finally, the behaviors of the test vehicle are selected by the behavior correlation matrix of the surrounding vehicle and the test vehicle. And the new scenarios by considering the behavior of vehicles in the avoidance area and the behavior of test vehicles are generated.
3. Based on the above scenarios, the environmental indicators of Level 9 are added. Environmental scenarios mainly include rainy, snowy, strong wind, and foggy weather. And the new scenarios for the night driving are generated by Level 9 and Level 10.

Table 1 Indicators of each level

Level 1	Scenario	Linear geometry			
	Indicators	Curve radius, curve corner, super high, widening, slope, slope length			
Level 2	Scenario	Cross section			
	Indicators	Road width, lane width, road shoulder, road smoothness, road anti-skid performance, maximum speed limit, minimum speed limit			
Level 3	Scenario	Intersection	Flyover	Bridge	Tunnel
	Indicators	Left-turn lane, right-turn lane, signal lights, traffic police command	Ramp curve radius, ramp longitudinal slope, ramp slope length, merging zone, diverging zone	Bridge head curve, bridge slope	Tunnel length, tunnel lighting
Level 4	Scenario	Road obstacles			
	Indicators	Road traffic accidents, moving objects on the road, construction occlusion			
Level 5	Scenario	Traffic signs and lines			
	Indicators	Warning sign, prohibition sign, mandatory sign, guide sign, tourist sign, road construction safety sign, auxiliary sign, no marking, indicating marking, warning marking			
Level 6	Scenario	Types of traffic participants			
	Indicators	Motor vehicles, motorcycles, bicycles, pedestrians			
Level 7	Scenario	Test vehicle behavior		Surrounding vehicle behavior	
	Indicators	Acceleration, deceleration, synchronization, go straight, cut in, cut out		Acceleration, deceleration, synchronization, go straight, cut in, cut out	
Level 8	Scenario	The second action of the test vehicle			
	Indicators	Emergency deceleration, emergency lane change			
Level 9	Scenario	Rain	Snow	Wind	Foggy
	Indicators	Rainfall, drainage	Snowfall, snowmelt degree	Wind force, wind speed, wind direction	Visibility, tire slip degree
Level 10	Scenario	Night driving			
	Indicators	Light intensity			

The specific algorithm steps of the functional scenario are as follows:

Step 1: Define parameter x_{ij}^{d} as 0–1 variable,

$$x_{ij}^{d} = \begin{cases} 1 & x_{ij} \text{ exist or function in the scene } d \\ 0 & or \end{cases}$$

Step 2: The indicators relationship set of the functional scenario is built based on the principle of multi-tree construction as follows.

Step 2.1: Define the index x_{ij} of each node, i is the Number of the level and the j is the Number of the indicators for each level.
Step 2.2: Add a domain for recording node names.
Step 2.3: Increase the array used to store the address of the child node.
Step 2.4: Read the data file and build a multi-tree.

Step 2.4.1: Reading start from the index with $i = 0$ and $j = 1$, name the index of this layer as the j-th layer index, and name the index of this layer as the parent node. Then read the next level child nodes of the j-th level indicator in turn.
Step 2.4.2: Determine the functional variables of the sub-node x_{ij} of the j-th level index.
Step 2.4.3: Let $:= j + 1$.
Step 2.4.4: Read each node index x_{ij} of the j-th level in turn, and assign each node index as a child node to its corresponding parent node in the j-1th level index.
Step 2.4.5: Judge whether the j-th layer is a bottom node, if it is, turn to Step 2.4.6, otherwise turn to Step 2.4.3.
Step 2.4.6: Let $i = i + 1$ ($i < = 10$) and turn to the Step 2.4.1.

Step 3: Based on the deep search algorithm for the multi-tree, by judging the value of the function variable, the function scenarios set is established.

Step 3.1: Define an empty set of functional scenario Z.
Step 3.2: Visit the vertex node of the multi-tree x_{01}.
Step 3.3: Starting from the currently specified starting vertex, if there is any adjacent vertex of the currently visited vertex that has not been visited, choose one to visit; otherwise, return to the most recently visited vertex until there is a path connected to x_{01} in the multi-tree. The nodes are all visited. And in the sequential access, the functional variables of $x_{ij} = 1$ are included in the variable set Z.
Step 3.4: Judge whether there are any nodes in the multi-tree that have not been visited at this time. If yes, choose one of the unvisited vertices as the starting vertex and visit it, turn to Step3.3, otherwise, turn to Step4 when the traversal ends.

Step 4: Update the functional scenario set Z.

4 Logic Scenarios Construction

By analyzing the specific parameters that can be collected from the actual environment, the distribution range of each parameter can be determined. And the distribution of each key parameter is calculated. Determine the value a% according to the value range of each parameter when generating a concrete scenario. That is the proportion of the statistical values of parameter needs more than a%. Based on the distribution, the continuous rate of change can be calculated and parameter range can be obtained.

Specific steps of logical scenario generation as follows:

Step 1: Select a certain functional scenario to generalize the logical scenarios.
Step 2: Extract and classify the relevant parameters of the functional scenario.

Step 2.1: Create two empty sets, set M and set N.
Step 2.2: Classify the extracted relevant parameters into two categories: basic function parameters that are not generalizable and variable parameters that can be generalized. List the non-generalizable basic function parameters into the set M, and list the generalizable variable parameters into the set N.

Step 3: Extract the parameter value of each generalizable variable parameter in the set N in the real environment in turn, and determine the range of each optional parameter set.

Step 3.1: The parameters in the set N are marked as i, and x_{i} represents the i-th parameter ($i = 1 \cdot \cdots \cdot n$).
Step 3.2: Set: $i = 0$.
Step 3.3: Let: $i = i + 1$.
Step 3.4: Extract the parameter value of parameter xi in the real environment.
Step 3.5: Perform numerical fitting on the obtained parameter values in the real environment to obtain the probability density function of the normal distribution $f(x)$.
Step 3.6: Determine the acceptable probability section of the parameter according to the parameter value of the probability distribution function had been obtained.
Step 3.7: Judge whether $i = n$, if it is, turn to Step4, otherwise, turn to Step3.3.

Step 4: According to the determined specific values of the parameters in the set N and the basic function parameter values in the set M, the logical scenarios can be obtained.

5 Concrete Scenarios Construction

According to the parameter distribution range analyzed above, the parameter change trend function and parameter probability are established. Let x_i represent the i-th parameter and $f(x_i)$ represent the probability density function of parameter x_i. The

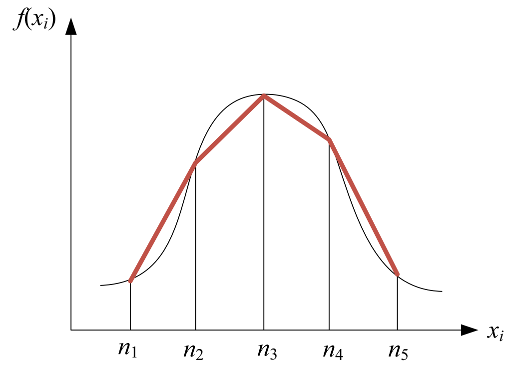


Fig. 1 Example of specific value selection method

density function can be extracted by the parameter extraction method in the logical scenario.

As shown in Fig. 1, take the normal distribution as an example. For the parameter distribution interval, it is equally divided into N parts. It is assumed that the selected number of parameters in each part obeys a uniform distribution. The number of specific parameters selected in the j-th part obeys the uniform distribution of U_j as Formula (1).

$$N_j = U_j(f(x_i)_{n_j}, f(x_i)_{n_{j+1}}), j = 1...N - 1 \tag{1}$$

According to the number of values and value ranges of each part, the specific values of the parameters are selected on average. And the concrete scenario can be obtained.

The interval section expression mode $[n_j, n_{j+1})(j = 1, 2, 3 \cdots\cdots)$ represents the value ranges of the j-th part. m_j is the number of values for the j-th part. The a_j is the value set of the j-th part represented by Formula (2). Set A is the total value set represented by Formula (3). If the value produces a decimal when dividing an integer, the decimal is rounded down to an integer.

$$\begin{aligned} a_j = \Big\{ & n_j, n_j + \frac{n_{j+1} - n_j}{m_j}, n_j + \frac{n_{j+1} - n_j}{m_j} * 2, n_j \\ & + \frac{n_{j+1} - n_j}{m_j} * 3, \cdots, \frac{n_{j+1} - n_j}{m_j} * (m_j - 1) \Big\} \end{aligned} \tag{2}$$

$$A = \{a_1, a_2, a_3, \cdots\} \tag{3}$$

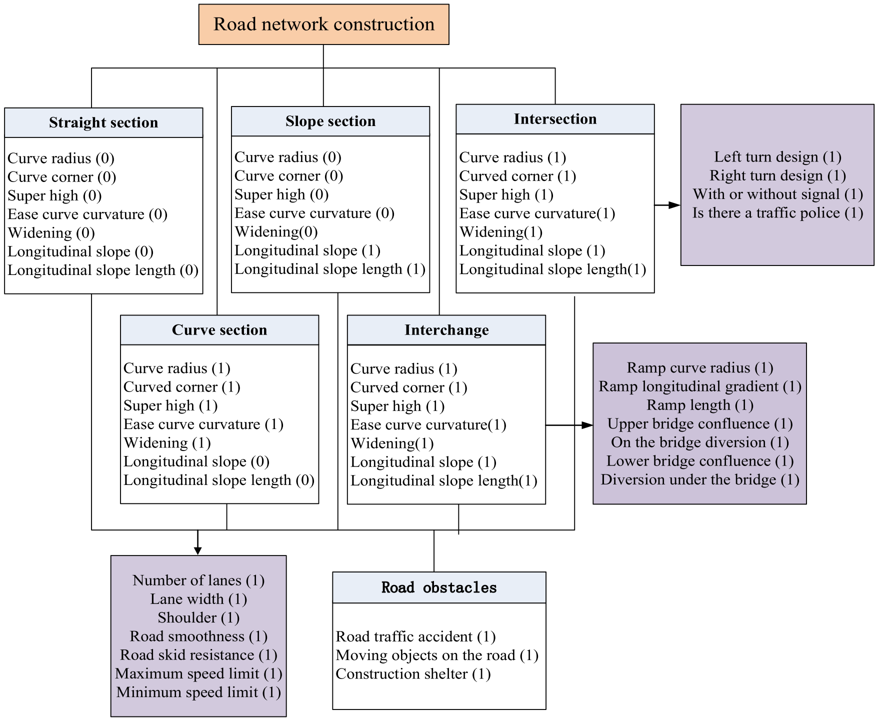


Fig. 2 Different road conditions for the functional scenarios

6 Case Study

6.1 Functional Scenario Generation

The functional scenario of different road conditions, traffic flow conditions, and environmental conditions can be generated by the methods shown in Figs. 2, 3, and 4.

6.2 Examples of Logical Scenarios Generalization

According to the functional scenario, the parameter value analysis is performed for the parameter whose value is 1 for each functional scenario. The generation method of logic scenario is analyzed by the traffic part of one functional scenario.

In order to explain the parameters' definition of the logical scenarios, the paper takes the scenario that the surrounding vehicle cuts in as the case to analyzing. As shown in Fig. 5, the black vehicle slows down and cuts into the front of the test red vehicle. For keeping a safe distance, the test vehicle needs to decelerate.

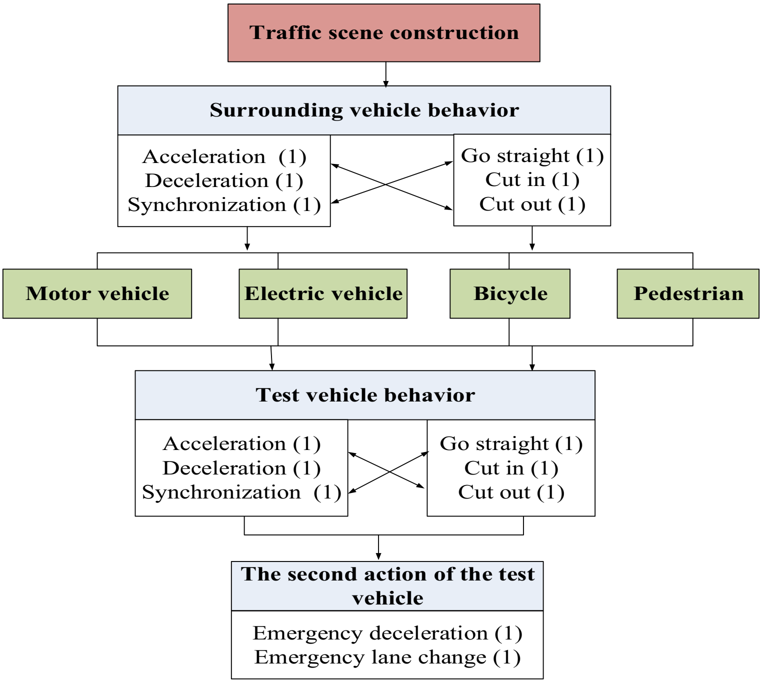


Fig. 3 Function scenario of different traffic conditions

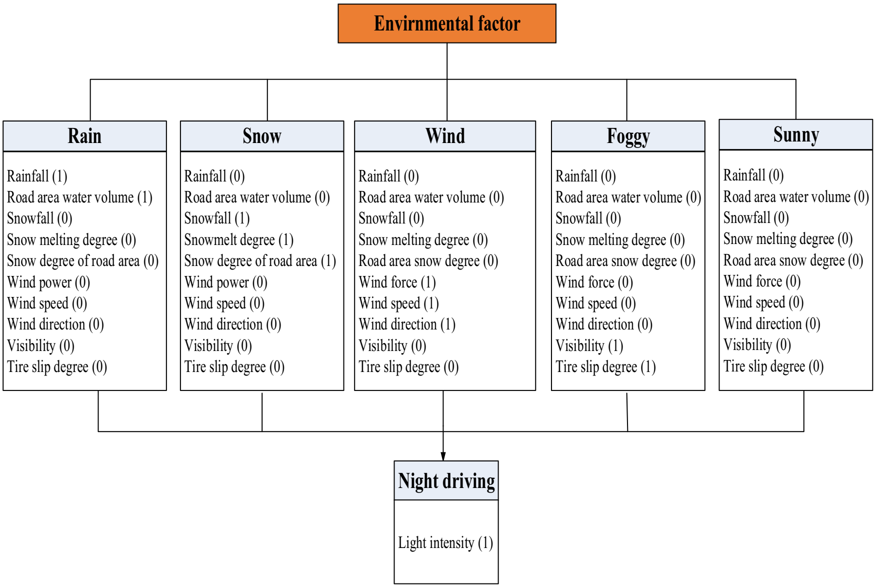


Fig. 4 Function scenario of different environment conditions

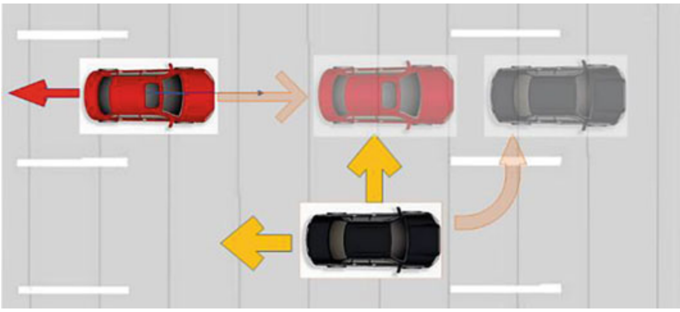


Fig. 5 Location relationship of the vehicles

The specific parameters required for this scenario include: the initial speed of the autonomous vehicle (V0), the initial lateral distance (Dy), the initial longitudinal distance (Dx) between the test vehicle and the surrounding vehicle, lateral velocity (Vy), and relative longitudinal velocity (Ve).

Based on the verification of real traffic data, the parameter distribution is automatically analyzed, and the concrete scenario parameter distribution is extracted. The distribution and range of cut-in scenario parameters are obtained by applying the automatic analysis process to the real traffic data.

For the above parameters, the distribution and value ranges of some of the available parameters are shown in Table 2. Take the proportion of the parameter as more than 5%. The value ranges of the following specific parameters are obtained as in Table 2.

6.3 *The Concrete Scenarios Generalization*

According to the logical scenario, the specific values of each parameter are analyzed for the concrete scenarios.

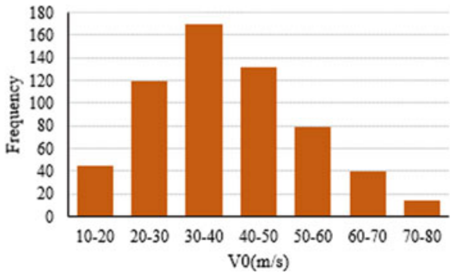
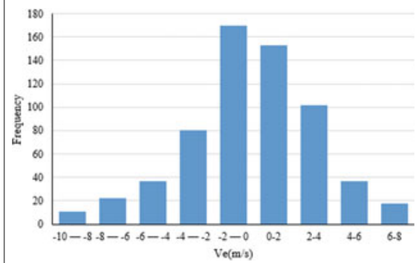
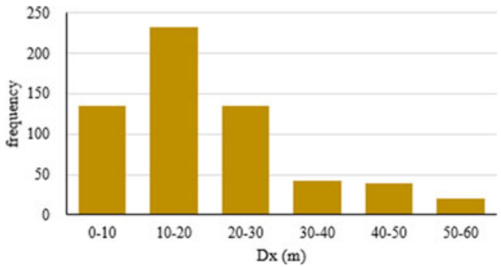
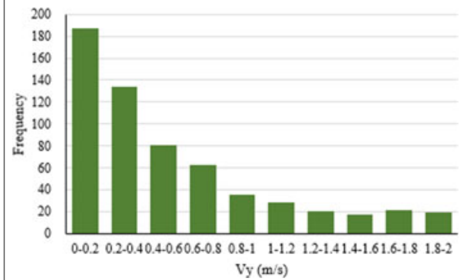
(1) Initial Vehicle Speed

The probability density function of the normal distribution can be obtained by the function distribution in Table 2 and can be calculated as: $f(v_0) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left(-\frac{(v_0-\mu)^2}{2\sigma^2}\right)$. The parameters can be obtained such as: $\mu = 37.23, \sigma = 14.96$. Therefore, the probability density function of this parameter is.

$$f(v_0) = \frac{1}{\sqrt{2\pi}14.96}\exp\left(-\frac{(v_0 - 37.23)^2}{2 \times (14.96)^2}\right)$$

The speed values are divided into 7 parts. The range of each part is 10. The probability density function is used to calculate the number of values in each speed part. Assume that the total value is 30, and the specific value in each speed interval is uniformly distributed.

Table 2 Parameter distribution and value range

Parameter	V0	Ve
Function distribution		
Range	10–80 km/h	−10––8 m/s
Parameter	Dx	Vy
Function distribution		
Range	0–60 m	0–7 m/s

(2) Relative Velocity of Vehicles

The probability density function of the normal distribution can be obtained by the function distribution in Table 2. The parameters can be obtained such as: $\mu = 0.094$, $\sigma = 2.875$. Therefore, the probability density function of this parameter is

$$f(v_0) = \frac{1}{\sqrt{2\pi}2.875} \exp\left(-\frac{(v_0 - 0.094)^2}{2 \times (2.875)^2}\right)$$

The relative speed values are divided into 9 parts. The range of each part is 2. Assume that the total value is 30, and the specific value in each relative speed part is uniformly distributed.

(3) Longitudinal Distance

Assuming that the initial distance of the vehicles obeys a uniform distribution, the distance value is divided into 6 parts, and the range of each part is 10. Then the number of values for each part is calculated as $n_x = N_{sum} * P_{ij}$ by the probability density function. Assume that the total value is 30.

(4) Lateral Velocity

Assuming that the initial distance of the vehicles obeys a uniform distribution, the distance value is divided into 10 parts, and the range of each part is 0.2. Then the number of values for each part is calculated as $n_x = N_{sum} * P_{ij}$ by the probability density function. Assume that the total value is 30.

(5) Scenarios Integration by Parameters' Relationship

According to the above results, the specific value range of each parameter has been obtained. When generalizing concrete scenarios, specific test scenarios can be obtained by sequentially taking values for each parameter. The relationship between the longitudinal distance between the two vehicles and the relative speed of the vehicle can be obtained by calculation as shown in Formula (4).

$$d_x = \frac{1}{2} * |v_0 - v_{e0}| * t \tag{4}$$

When determining the specific value of each parameter, the initial speed of the vehicle can be selected from the specific value set in Table 3 (in this study, it is assumed that the initial speed of each vehicle is the same), and the relative speed of the two vehicles can be selected from the specific value set in Table 4. The longitudinal distance between the two vehicles can be calculated from the selected vehicle relative speed and Formula (4). The calculated longitudinal distance is corrected according to the values listed in the specific value set in Table 5, and the value is ±0.3. (If the difference between the calculated longitudinal distance and a certain value listed in the specific value set in Table 5 is between ± 0.3 (including ± 0.3), the calculated longitudinal distance is set as the acceptable vehicle longitudinal distance.) The value of each parameter in some concrete scenarios is shown in Table 3.

Table 3 Values of various parameters in some concrete scenarios

No.	Initial vehicle velocity (km/h)	Velocity of vehicles (m/s)	Longitudinal distance between two vehicles (m)	Number of concrete scenarios
1	15, 20, 22, 23, 25, 27, 28, 30, 31, 33, 34, 35, 36, 38, 39, 40, 41, 43, 44, 46, 47, 49, 50, 53, 55, 58, 60, 65, 70, 80	±6	3.3, 14.8, 18, 24.2, 27, 29.8, 45	30 * 2 * 7
2		±4	1.7, 8.3, 10, 14, 18, 24.2, 29.8, 40, 50	30 * 2 * 9
3		±3	1.7, 3.3, 10.8, 13.2, 14.8, 16.4, 18, 19.6, 22.8, 24.2, 25.6, 27, 28.4, 29.8, 45	30 * 2 * 15
4		±1.5	1.7, 3.3, 5, 6.7, 8.3, 10, 10.8, 13.2, 14, 14.8, 15.6, 16.4, 17.2, 18, 18.8, 19.6, 22.8, 24.2, 25.6, 27, 28.4, 29.8, 35, 40, 45, 50, 55	30 * 2 * 27
5		±0.5	1.7, 3.3, 5.0, 6.7, 8.3, 10, 10.8, 11.6, 12.4, 13.2, 14, 14.8, 15.6, 16.4, 17.2, 18, 18.8, 19.6, 21.4, 22.8, 24.2, 25.6, 27, 28.4, 29.8, 35, 40, 45, 50, 55	30 * 2 * 30
6		±1.14	1.7, 3.3, 5, 6.7, 8.3, 10, 10.8, 11.6, 12.4, 13.2, 14, 14.8, 15.6, 16.4, 17.2, 18, 18.8, 19.6, 21.4, 22.8, 24.2, 25.6, 27, 28.4, 29.8, 35, 40, 45, 50, 55	30 * 2 * 30
7		±3.2	1.7, 3.3, 5.0, 6.7, 8.3, 24.2, 25.6, 27, 35, 40, 45	30 * 2 * 11
8		±8	8.3, 24.2, 40	30 * 2 * 3

Table 4 Relative speed value

Relative velocity (km/h)	Probability	Number of values	Correction number	Specific value set (km/h)
[−10 ~ −8]	0.017	1	0	{−}
(−8 ~ −6]	0.035	1	1	{6}
(−6 ~ −4]	0.059	2	2	{−5, −4}
(−4 ~ −2]	0.127	4	4	{−3.5, −3, −2.5, −2}
(−2 ~ 0]	0.270	8	8	{−1.75, −1.5, −1.25, −1, −0.75, −0.5, −0.25, 0}
(0 ~ 2]	0.243	7	7	{0.29, 0.57, 0.86, 1.14, 1.43, 1.71, 2}
(2 ~ 4]	0.162	5	5	{2.4, 2.8, 3.2, 3.6, 4}
(4 ~ 6]	0.059	2	2	{5, 6}
(6 ~ 8]	0.029	1	1	{8}

Table 5 Longitudinal distance value

Longitudinal distance (m)	Frequency	Probability	Number of values	Specific value set (m)
[0–10]	135	0.2246	6	{1.7, 3.3, 5.0, 6.7, 8.3, 10}
(10–20]	232	0.3851	12	{10.8, 11.6, 12.4, 13.2, 14, 14.8, 15.6, 16.4, 17.2, 18, 18.8, 19.6}
(20–30]	135	0.2246	7	{21.4, 22.8, 24.2, 25.6, 27, 28.4, 29.8}
(30–40]	42	0.0697	2	{35, 40}
(50–60]	39	0.0642	2	{45, 50}
(50–60]	20	0.0323	1	{55}

7 Conclusion

With the rapid development of autonomous driving technology, the testing and evaluation of autonomous vehicles have become a key issue in technology development. And scenario-based testing methods have become an important problem for autonomous driving technology. This paper studied the generalization method of test virtual scenario for autonomous vehicles. The scenarios were divided into functional scenarios, logical scenarios, and concrete scenarios. The theoretical methods for generating the different types of test scenarios were introduced. This method can make the test for autonomous vehicles easily and quickly by the virtual simulation. And the tester can establish test scenarios and obtain scenario data with a short time and small cost.

Acknowledgements This research is supported by project TC210H02S.

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