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Regression Machine Learning Models for the Short-Time Prediction of Genetic Algorithm Results in a Vehicle Routing Problem

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Abstract: Machine learning techniques have advanced rapidly, leading to better prediction accuracy within a short computational time. Such advancement encourages various novel applications, including in the field of operations research. This study introduces a novel way to utilize regression machine learning models to predict the objectives of vehicle routing problems that are solved using a genetic algorithm. Previous studies have generally discussed how (1) operations research methods are used independently to generate optimized solutions and (2) machine learning techniques are used independently to predict values from a given dataset. Some studies have discussed the collaborations between operations research and machine learning fields as follows: (1) using machine learning techniques to generate input data for operations research problems, (2) using operations research techniques to optimize the hyper-parameters of machine learning models, and (3) using machine learning to improve the quality of operations research algorithms. This study differs from the types of collaborative studies listed above. This study focuses on the prediction of the objective of the vehicle routing problem directly given the input and output data, without optimizing the problem using operations research algorithms. This study introduces a straightforward framework that captures the input data characteristics for the vehicle routing problem. The proposed framework is applied by generating the input and output data using the genetic algorithm and then using regression machine learning models to predict the obtained objective values. The numerical experiments show that the best models are random forest regression, a generalized linear model with a Poisson distribution, and ridge regression with cross-validation.

Keywords: vehicle routing problem; genetic algorithm; prediction; regression machine learning; smart logistics

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1. Introduction

In recent years, machine learning studies have advanced rapidly and encouraged collaboration with various research fields, including the operations research field. There are several main frameworks used when conducting research in both areas simultaneously. The first framework applies machine learning techniques to predict input data for operations research problems. One application is estimating the energy consumption of electric vehicles on different paths and routes before solving the routing problem [1]. Another application is clustering flights based on the similarity in the working crews before solving the flight connection optimization problem [2]. The last example is predicting the demand for cash transportation between bank branches based on historical data and calendar information before determining the transportation schedules [3]. A review of this first framework can be observed in [4].

The second framework applies operations research techniques to optimize the machine learning method's results. Some examples are (1) using differential flower pollination metaheuristics to optimize the hyper-parameters of a support vector machine model for image-processing-based pavement condition observation [5] and (2) using the firefly algorithm to optimize the hyper-parameters in a support vector regression machine learning model used for the prediction of a building's energy consumption level [6]. A recent review of this type of study is presented in [7]. It shows that such research with such a framework is still rare.

The third framework applies machine learning models to improve the quality of operations research models. The first category in this framework is using machine learning methods (e.g., reinforcement learning) to find the best operator in metaheuristics, as described in a recent review [7]. The second category in this framework is using machine learning to improve the quality of operations research methods. Two examples are (1) using a decision tree to differentiate poor and good vehicle routing problem solutions [8] and (2) using machine learning techniques to select bins in a stochastic bin packing problem considering various features (the bin's capacity, the reduced cost, and variable values in the relaxed version of the optimization problem) [9].

Despite the continuous growth in machine learning studies in various fields and the development of numerous operations research techniques, collaboration between the machine learning and operations research fields is still in its initial phase. As mentioned in [10], most of the proposed machine learning methods have not yet been applied to solve vehicle routing problem variants, one of the most studied topics in operations research.

Machine learning was used by Arnold and Sörensen [8] to extract important features and develop a problem-specific decision tree. It opened up the opportunity to design heuristics with good knowledge of the studied problem. However, their approach still required the development and running of heuristics. Differing from the three frameworks mentioned above, this study introduces a more general framework that could be used to predict the results of a solution method given an operations research problem without running an operations research algorithm. Such a situation is encountered when the decision-makers need to predict the system's behavior without waiting for long periods of computational time. This prediction is important before making any related decisions. As an example, after the decision-makers predict the total travel times of trucks, they could measure how much energy (gasoline or electricity) is consumed for deliveries and possibly solve another follow-up optimization problem, e.g., (1) determining the number of energy supply centers to locate within the area and (2) allocating trucks to energy supply centers, to ensure that the trucks run smoothly.

The proposed framework could also be applied when data are generated based on (1) the decision-maker's knowledge or (2) historical data without any of the solution method's information. The broad implementation of the proposed framework is thus possible. Implementing the framework for such practical data could be beneficial when it is difficult for managers (as decision-makers) to install the required computational systems to run the optimization models [11]. For ease of understanding, this study demonstrates the proposed framework when solving the vehicle routing problem (VRP) using the genetic algorithm (GA) method.

A framework for the use of machine learning techniques to observe the behavior of operations research models (discussed in this study) has been suggested in recent studies [12,13]. De Bock et al. [12] listed the steps as follows: (1) data generation and pre-processing, (2) machine learning model selection for the processing of the data, and (3) the interpretation of the model running results, including a feature importance analysis and rule extraction. Although De Bock et al. [12] presented such a data generation framework, they [12] did not specify any details regarding (1) which method should be used for data generation and (2) how the data generation and the machine learning model's running should be conducted when solving a specific case study. Different from [12], this study proposes a detailed framework for data generation using a specific operations research method and demonstrates how the proposed framework could be applied to solve a specific operations research problem. Different from [13], which proposed a classification-model-based prediction framework for a scheduling problem with several simple rules, this study proposes a framework for the routing problem that is solved using metaheuristics and predicted using regression machine learning models.

The structure of this study is as follows. Section 2 describes the proposed framework used to solve the operations research problem using regression machine learning techniques. Section 3 explains the case study: the VRP solved with the GA. Section 4 presents the numerical experiment's results. Section 5 explains managerial insights related to the implementation of the framework and lists possible applications of the proposed framework. Section 6 concludes the study.

2. Proposed Operations Research Problem Solving Using Machine Learning (OpReMaL) Framework

The solution of operations research problems is usually evaluated based on two performance indicators: (1) the solution quality regarding the best objective value and (2) the computational time. Although many solution methods are available, it is common practice to initially solve the problem using a mathematical model to obtain the optimal solutions for small-sized problems. The problems that arise when using a mathematical model to solve larger-sized problems are (1) the long computational time and (2) the possibility of not obtaining any feasible solution due to the complexity of the model. Therefore, various methods that obtain slightly worse solutions but during a much shorter computational time are applied, e.g., algorithms and metaheuristics [14].

In general, to obtain good-quality solutions, running any method for a longer computational time is necessary. Even though, in general, algorithms and metaheuristics require much less computational time than mathematical models, these methods might still need a long computational time to obtain solutions for larger-sized problems. As a consequence, it is necessary to develop a fast way to conduct real-time prediction and deal with the data generation process, which is costly [12]. This study resolves this long computational time issue by replacing the initial solution generation method, which is the operations research method (e.g., metaheuristics), with regression machine learning models. This study proposes the Operations Research Problem Solving Using Machine Learning (OpReMaL) framework, which is illustrated in Figure 1. The framework consists of (Step 1) the running of the operations research method to generate the input and output data and (Step 2) the running of the machine learning model to predict the generated output data based on the input data.

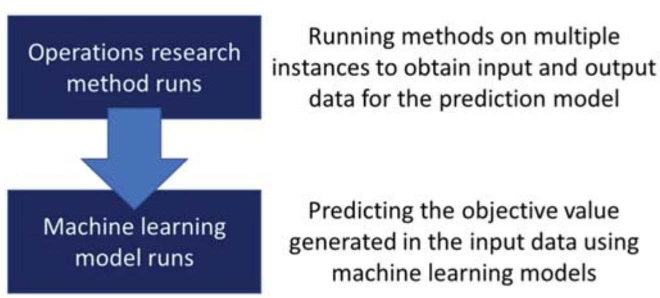

Figure 1. The proposed Operations Research Problem Solving Using Machine Learning (OpReMaL) framework.

In the first step of the OpReMaL framework (Figure 1), the operations research method is run for several instances to produce input and output data. An instance refers to a single operations research problem (with a set of problem parameters), generally solved to obtain a single best solution. The input is related to the characteristics of the problem;

meanwhile, the output refers to the objective value obtained after running a given solution method, e.g., metaheuristics. The OpReMaL framework could be considered a black box. The system represented by the black box is assumed to have a single means to generate the optimization solution. In practice, decision-makers could have (1) a method that generates a single solution for each instance or (2) a method that generates multiple solutions that would later be further evaluated for the final decision-making. This study considers the former. The generated input and output data will then be used to train the machine learning method.

In the second step of the framework (Figure 1), the machine learning model is trained and then used to predict the objective value in a much shorter time than when running operations research methods. The machine learning models predict the single objective value provided for each instance. When multiple objective values are considered, modifications could be performed with either of two options. The first involves preprocessing multiple objective values into a single weighted objective value. It includes the case in which the total costs are measured as a single value [15]. The second is applying the framework as many times as the number of objectives (and then selecting the best solution in the post-processing stage, e.g., using Pareto front analysis).

The OpReMaL framework starts with the operations research method, which is followed by the running of the machine learning model. During the real-time prediction process, the trained machine learning model is used directly within a very short prediction time. Such a situation occurs under the condition that the historical data size is already sufficiently large and there is no fundamental change in the problem parameters. On the contrary, when a new set of parameters is introduced into the problem, e.g., a new area of customers with different characteristics from the original ones, the whole framework (the operations research method and the machine learning model training) would need to be executed again.

3. Case Study: Vehicle Routing Problem Resolved Using Genetic Algorithm

3.1. Vehicle Routing Problem Resolved Using Genetic Algorithm (VRP-GA)

To show the effectiveness of the proposed OpReMaL framework, this study considers the case of the VRP that is resolved using the GA. The considered VRP is illustrated in Figure 2. Given the number of customers that must be visited and whose demand must be satisfied, multiple truck delivery routes are determined. The VRP considers that all homogeneous trucks (with the same capacity) start and end their travel from a single depot (node 0). The objective is to minimize the total travel times of all trucks. The mathematical model for this well-known VRP is presented in [16].

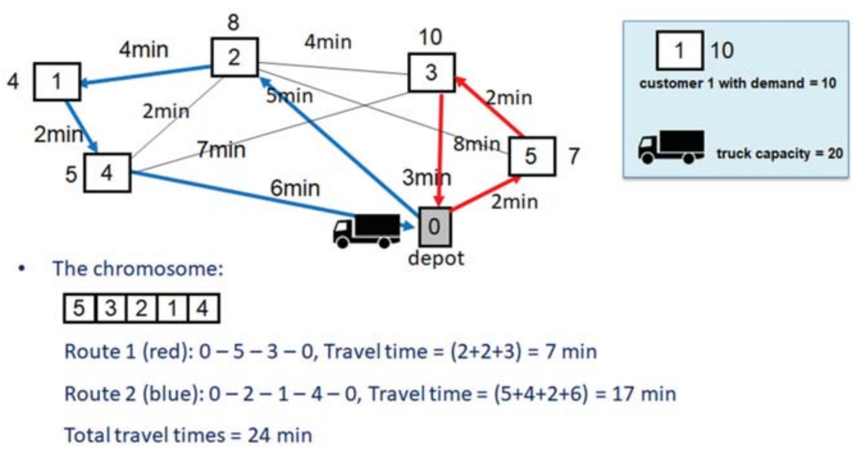

Figure 2. The considered vehicle routing problem.

The chromosome in Figure 2 represents a single solution. Given the sequence of customers to be visited by the truck, each route is constructed by subsequently adding customers while calculating the total amount of items transported by the truck. Before the truck capacity is violated, a single truck route generation step is completed, and then another truck is scheduled to satisfy the next customer's demands. In the considered VRP, the truck starts and ends at the depot.

The GA used to solve the VRP is shown in Figure 3. The GA uses the solution representation shown in Figure 2. The algorithm starts by randomly generating *population_size* chromosomes in the initial population. The objective value of each chromosome is calculated. Next, new solutions are generated through crossover and mutation operations within *num_of_population* populations.

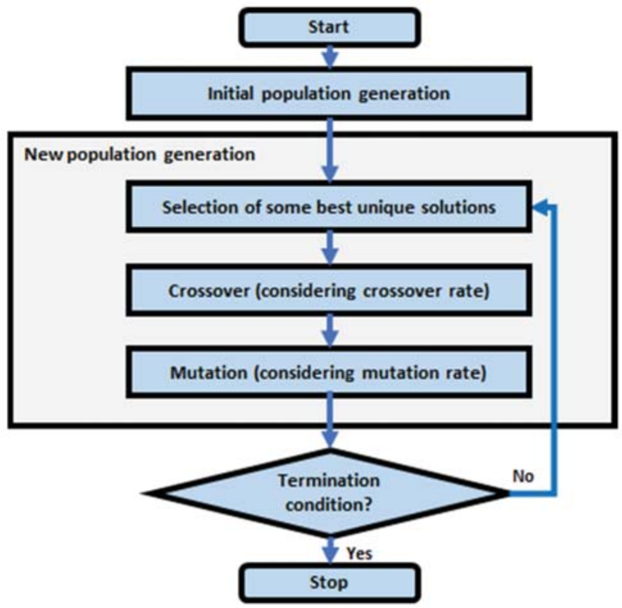

Figure 3. The genetic algorithm that is used to solve the vehicle routing problem.

In each population, the new solution generation process is conducted as follows (Figure 3): (1) selecting some best solutions (to be used as parent chromosomes during the crossover operation), (2) applying the crossover operator, and (3) applying the mutation operator. In part (1), a total of less than or equal to *num_of_selected_initial_chromosomes* unique best chromosomes are selected from the latest population. Next, each of the selected best chromosomes is given a selection probability (to be a parent chromosome) using the objective value conversion formula presented in Equation (1). The selection probability of each chromosome is then calculated using Equation (2). These equations set solutions with shorter travel times to have a larger selection probability.

$$inverted\_objective\_value = \frac{1}{objective\_value} \tag{1}$$

$$selection\_probability = \frac{inverted\_objective\_value}{\text{total } inverted\_objective\_value \text{ of all best chromosomes}} \tag{2}$$

When applying the crossover operator in part (2), two parent chromosomes are selected randomly based on the selection probabilities. After selecting these two parent chromosomes, a random number between 0 and 1 is generated. The crossover operator is applied if the random number is less than the *crossover_rate*. Otherwise, the parent chromosomes are stored as the result of the crossover operation. The outputs of the crossover operation are called child chromosomes. After applying the crossover operator, the two best chromosomes between two parent and two child chromosomes are selected to be stored in the new population. Given the *num_of_selected_initial_chromosomes* initial best chromosomes that are already stored in the new population, more chromosomes are generated during the crossover operation until the new population is filled with *population_size* chromosomes.

Given the *population_size* chromosomes in the new population, in part (3), each chromosome in the new population is further processed by applying the mutation operator. After selecting one parent chromosome using the selection probability in Equation (2), a random number between 0 and 1 is generated. The mutation operator is applied if the random number is less than the *mutation_rate*. Otherwise, the parent chromosome is stored as the result of the mutation operation. After applying the mutation operator, the child chromosome is selected to be stored in the new population, even though its objective value is worse than the parent chromosome. Such a selection is allowed in order to ensure good exploration while generating new solutions. The convergence of the GA is encouraged by selecting the best chromosomes before applying the crossover operator.

The crossover and mutation operators are illustrated in Figure 4. In the crossover operation, two-point crossover is applied. Two cutting points are randomly selected within the parent chromosomes. The customer numbers at the middle of the cutting points are copied into the child chromosomes (the red and blue highlighted parts in Figure 4). The remaining parts in each child chromosome are copied from the other parent chromosome. The remaining customer numbers are copied from left to right until all customer numbers are inserted into the child chromosomes. The mutation operation is applied by randomly selecting two customer numbers and exchanging their positions to produce the child chromosome.

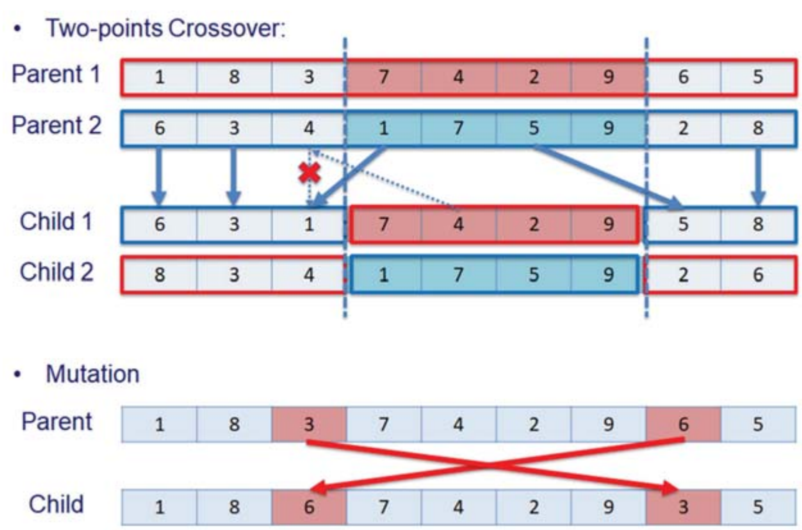

Figure 4. The crossover and mutation operators that are applied in this study.

3.2. Operations Research Problem Solving Using Machine Learning (OpReMaL) Framework Using Regression Machine Learning Models for the VRP-GA Case Study

In this study, regression machine learning models are used to predict the objective value of the VRP-GA (the total distances traveled by the trucks). The list of input and output data is shown in Figure 5. The input data represent the characteristics of each vehicle routing problem instance. Each input datum is presented as follows.

- *min_distance_depot*: the minimum distance between all customer–depot pairs;
- *average_distance_depot*: the average distance between all customer–depot pairs;
- *max_distance_depot*: the maximum distance between all customer–depot pairs;
- *min_distance_nondepot*: the minimum distance between all customer pairs, excluding the depot;
- *average_distance_nondepot*: the average distance between all customer pairs, excluding the depot;

- *max_distance_nondepot*: the maximum distance between all customer pairs, excluding the depot;
- *min_demand*: the minimum demand value among all customers;
- *average_demand*: the average demand value of all customers;
- *max_demand*: the maximum demand value among all customers;
- *num_customers*: the number of customers considered in the instance;
- *vehicle_capacity*: the capacity of homogeneous trucks.

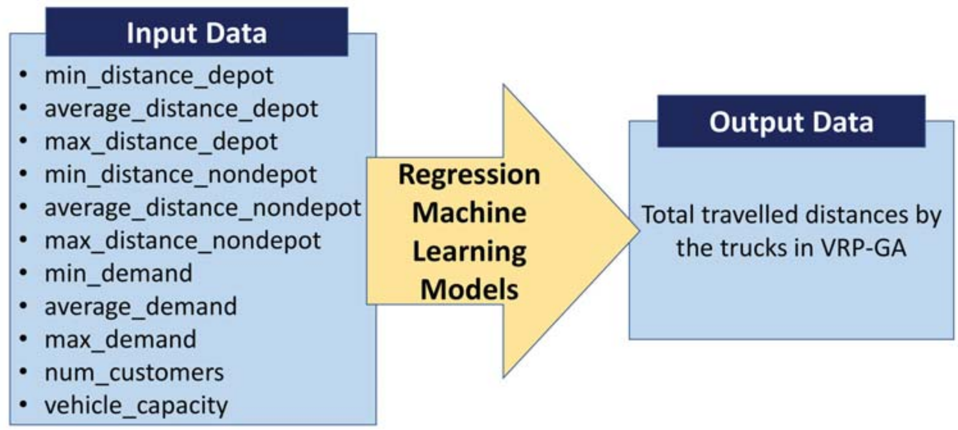

Figure 5. The input and output data used for the regression machine learning models.

Based on the best result obtained using the GA for each VRP instance, the regression machine learning models are applied to predict the total traveled distances of the trucks. The regression machine learning model is expected to predict the objective value of the VRP in a much shorter time than when using the GA.

4. Numerical Experiments

For the first step in the proposed framework (Figure 1), the data are generated using the GA. The characteristics of the problem instances and the GA parameter settings used in the numerical experiments are listed in Table 1. Other general characteristics and settings in all instances are listed in Table 2. Initially, a 1000×1000 map is generated, and then the customer coordinates in the x and y axes are determined randomly. The coordinates are then used to measure the Euclidean distances between the customers. A value for the capacity of the homogeneous trucks is selected randomly for each instance. The objective values of the VRP are calculated using the GA. The data can be accessed online at https://ubaya.id/vrp_ga_input_output (accessed on 2 December 2023). Considering various sets of instances for the machine learning prediction could offer a means to resolve the overfitting situation (which is caused by focusing only on one set of instances).

Table 1. The specific characteristics of the instances and the genetic algorithm parameter settings used in the numerical experiments.

Set of Instances	Number of Instances	Number of Customers [1]	*population_size*	*num_of_selected_initial_chromosomes*	*num_of_populations*	Average Computational Time Using the GA (s)
Set 1	2000	[10, 100]	50	30	50	4
Set 2	2000	[201, 300]	50	30	50	16
Set 3	500	[401, 500]	100	50	100	181
Set 4	50	[601, 700]	200	80	200	1811

[1] [minimum value, maximum value].

Table 2. The general characteristics of the instances and the genetic algorithm parameter settings used in the numerical experiments.

Characteristic or Parameter	Value
Map width (square area)	1000
Customer demand	[30, 100]
Homogeneous truck capacity	300, 400, or 500
crossover_rate	0.8
mutation_rate	0.2

For the second step in the proposed framework (Figure 1), the output data are predicted using regression machine learning models without solving the optimization problem again. Several regression machine learning models are tested, and then the best models are reported in this section. The following regression machine learning models from scikit-learn [17] are used for the predictions: (1) random forest regression, (2) linear regression, (3) RidgeCV, (4) ElasticNetCV, (5) LarsCV, (6) LassoCV, (7) LassoLarsCV, (8) OrthogonalMatchingPursuitCV, (9) ARDRegression, (10) BayesianRidge, (11) HuberRegressor, (12) RANSACRegressor, (13) TheilSenRegressor, (14) PoissonRegressor, (15) TweedieRegressor, (16) GammaRegressor, and (17) PassiveAggressiveRegressor. At the time of writing, scikit-learn has more than 90,000 citations based on Google Scholar. Its minimal dependencies and ease of use allow a high reproducibility rate in many studies. Each regression machine learning model is described in Table 3.

Table 3. Explanations of each regression machine learning model.

Regression Machine Learning Model	Explanation
(1) Random Forest Regression	An ensemble method consisting of some decision trees. It considers the decision trees' diversity when making decisions [18].
(2) Linear Regression	A linear equation used to represent relationships between variables, generated based on the observed data [19].
(3) RidgeCV	A multiple linear regression with a reduction in the weights of unimportant coefficients (ridge regression) and cross-validation. It allows the greater generalization of the prediction model [20,21].
(4) ElasticNetCV	A regularization method that eliminates the redundancy of variables. It has some penalty terms that are used as a compromise strategy between the LASSO and ridge regression techniques [22]. ElasticNetCV is an ElasticNet with cross-validation [21].
(5) LarsCV	A linear regression machine learning model that starts with all coefficients equal to 0 and then gradually updates the coefficients after identifying the most correlated input with the output data. It is very efficient because of its piecewise linear solution paths [23]. LarsCV applies cross-validation [21].
(6) LassoCV	A linear regression machine learning model with the least absolute shrinkage and selection operator (LASSO) that selects variables and determines regression coefficients simultaneously in one step [24]. LassoCV applies cross-validation [21].
(7) LassoLarsCV	A cross-validated LASSO, applied in the LARS algorithm [21].
(8) OrthogonalMatchingPursuitCV	A method that iteratively selects the feature that has the largest correlation with the current residual. Each selected feature will then be projected to the span of selected features. The iteration continues until K columns are selected [25]. It applies cross-validation [21].

Table 3. *Cont.*

Regression Machine Learning Model	Explanation
(9) ARDRegression	A Bayesian model with automatic relevance determination that prunes redundant features by estimating the parameters of the data distribution based on a maximum likelihood consideration [26].
(10) BayesianRidge	A Bayesian method that considers a common variance for all regression coefficients [27].
(11) HuberRegressor	A regression machine learning model that is robust to outlier data due to considering a linear loss for such outlier data [21].
(12) RANSACRegressor	An iterative algorithm that conducts the robust estimation of parameters based on inliers from the data after randomly extracting matching points. The inliers are determined based on a threshold [21,28].
(13) TheilSenRegressor	A median-based estimator that uses generalization in multiple dimensions, allowing it to be robust to multivariate outliers [21].
(14) PoissonRegressor	A generalized linear model that considers the dependent variables to be independent and random variables that follow a Poisson distribution [29].
(15) TweedieRegressor	A generalized linear model that considers the dependent variables to be independent and random variables that follow a Tweedie distribution [21].
(16) GammaRegressor	A generalized linear model that considers the dependent variables to be independent and random variables that follow a Gamma distribution [21].
(17) PassiveAggressiveRegressor	An online learning regression machine learning model that learns data that are added continuously [30]. It is suitable for large-scale learning [21].

The regression machine learning models are evaluated via the mean absolute error (MAE) values, as shown in Figure 6. The three best models with the lowest MAE values are random forest regression (2216.86), HuberRegressor (4940.09), and ARDRegression (5013.01). The average objective value of all instances is 98,576.

The regression machine learning models are evaluated via the mean squared error (MSE) values, as shown in Figure 7. The three best models with the lowest MSE values are random forest regression (12,204,263.19), ARDRegression (51,956,577.89), and TheilSenRegressor (58,285,906.56). The regression machine learning models are evaluated via the root mean squared error (RMSE) values, as shown in Figure 8. The three best models with the lowest RMSE values are random forest regression (3493.46), TheilSenRegressor (7634.52), and PassiveAggressiveRegressor (9610.48). A list of all MAE, MSE, and RMSE values for each model is shown in Table 4. The experiments with the MAE, MSE, and RMSE metrics show that the best model is random forest regression.

To further evaluate the proposed framework, the prediction is conducted when considering each set of instances (in Table 1) separately. The best MAE value, the average objective value, and the best regression machine learning model when considering each set of instances are shown in Table 5. The prediction quality is good because the deviation measured by the best MAE in contrast to the average objective value is less than 5% for each set of instances. When compared with the results in Figure 6, the best model is not always the same. It could be concluded that it is necessary to apply different regression machine learning models for each set of instances (Table 5). This would allow a better prediction to be produced, rather than considering instances from all sets simultaneously

(Figure 6). However, the decision-maker could still consider using the whole set of data to apply a more general method for the problem characteristics.

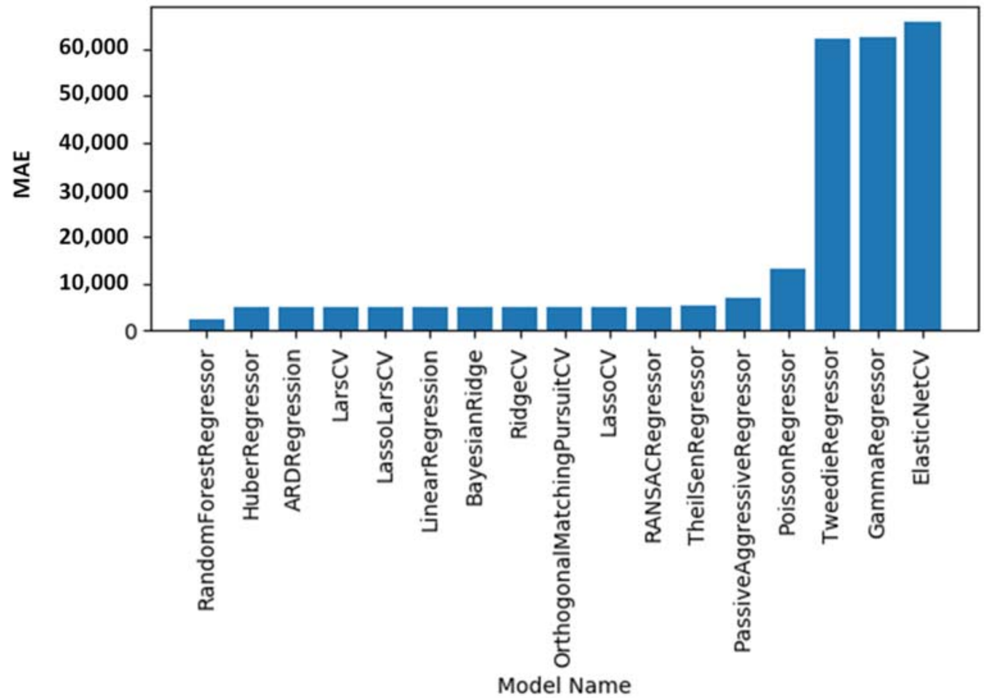

Figure 6. Performance of all regression machine learning models (with mean absolute error metric).

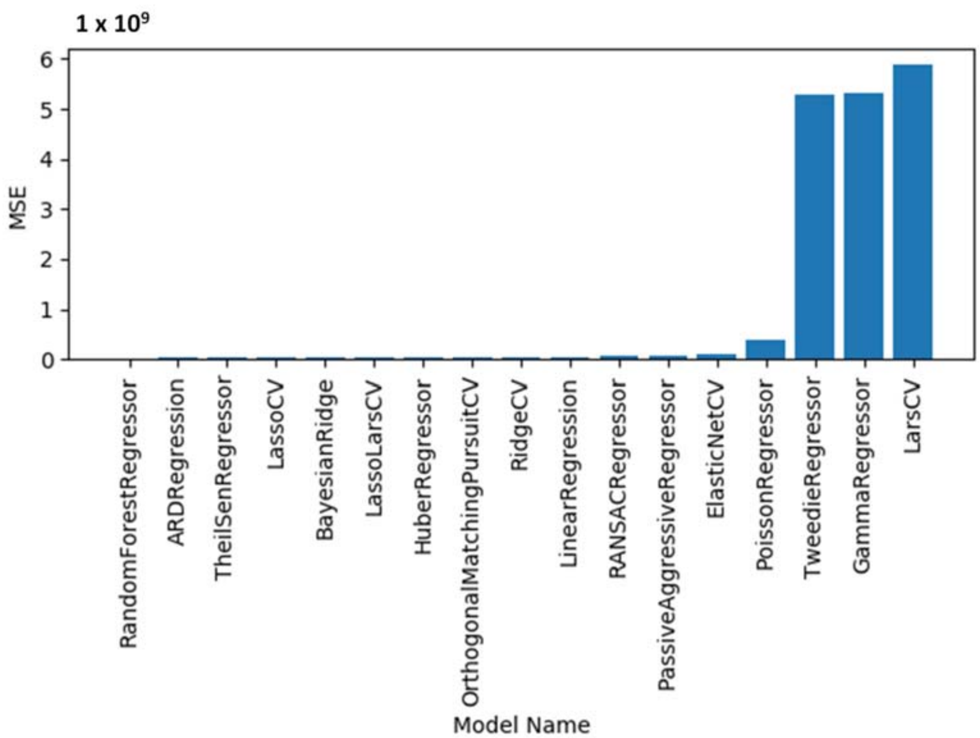

Figure 7. Performance of all regression machine learning models (with mean squared error metric).

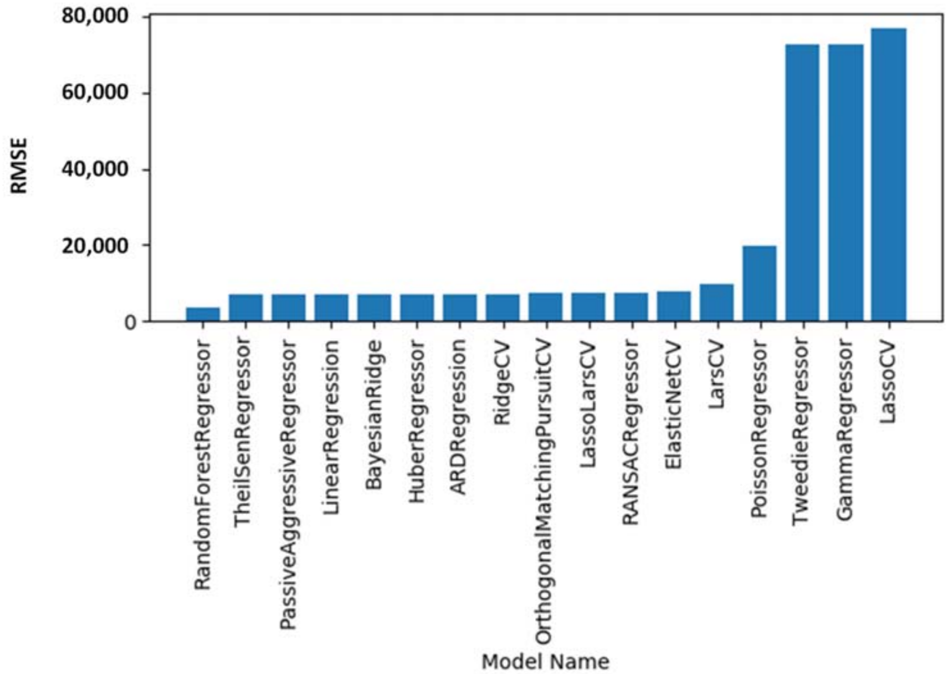

Figure 8. Performance of all regression machine learning models (with root mean squared error metric).

Table 4. Performance metrics for each regression machine learning model when considering all data instances.

Regression Machine Learning Model	MAE	MSE	RMSE
(1) Random Forest Regression	*** 2216**	*** 12,204,263**	*** 3493**
(2) Linear Regression	5013	51,871,442	7202
(3) RidgeCV	5015	51,800,637	7197
(4) ElasticNetCV	65,859	5,903,239,905	76,832
(5) LarsCV	5013	51,871,442	7202
(6) LassoCV	5038	52,427,706	7240
(7) LassoLarsCV	5013	51,871,442	7202
(8) OrthogonalMatchingPursuitCV	5037	52,412,692	7239
(9) ARDRegression	5013	51,956,577	7208
(10) BayesianRidge	5013	51,868,066	7201
(11) HuberRegressor	4940	56,948,824	7546
(12) RANSACRegressor	5043	51,806,962	7197
(13) TheilSenRegressor	5369	58,285,906	7634
(14) PoissonRegressor	13,100	397,203,436	19,929
(15) TweedieRegressor	62,313	5,299,130,027	72,795
(16) GammaRegressor	62,694	5,312,249,478	72,885
(17) PassiveAggressiveRegressor	6847	92,361,365	9610

*** Best performance value for each metric.**

Table 5. MAE values when each set of instances is considered separately.

Set of Instances	Best MAE	Average Objective Value	Best Model	Computational Time (s)
Set 1	932.58 (3.8%)	24,863	Random Forest Regression	2
Set 2	2142.51 (1.6%)	132,821	PoissonRegressor	<1
Set 3	3839.04 (1.6%)	234,490	PoissonRegressor	<1
Set 4	3452.44 (1.1%)	318,115	RidgeCV	<1

Each of the best regression machine learning models requires less than two seconds for its training. Using any regression machine learning model, the objective value prediction of any instance could be conducted within less than one second. When compared with the computational time presented in Table 1, the objective value prediction using the regression machine learning model is up to 1800 times faster than when the objective values are calculated using the GA, especially when dealing with large-sized problems. Further evaluations using each set of instances when using the MSE and RMSE are shown in Tables 6 and 7, respectively. The experiments with the MAE, MSE, and RMSE metrics show that the best models are random forest regression (for Set 1), PoissonRegressor (for Set 2), PoissonRegressor (for Set 3), and RidgeCV (for Set 4).

Table 6. MSE values when each set of instances is considered separately.

Set of Instances	Best MSE	Best Model	Computational Time (s)
Set 1	1,456,221.20	Random Forest Regression	2
Set 2	7,513,768.98	PoissonRegressor	<1
Set 3	23,010,249.50	PoissonRegressor	<1
Set 4	18,644,231.03	RidgeCV	<1

Table 7. RMSE values when each set of instances is considered separately.

Set of Instances	Best RMSE	Best Model	Computational Time (s)
Set 1	1206.74	Random Forest Regression	2
Set 2	2741.13	PoissonRegressor	<1
Set 3	4796.90	PoissonRegressor	<1
Set 4	4317.90	RidgeCV	<1

5. Managerial Insights and Potential Applications

The proposed OpReMaL framework was designed to predict the objective values of operations research problems. Different operations research problems have different problem characteristics (which would be considered as the input data). When generating the objective value as the output data, a specific operations research method would be applied to the set of input data. When solving each specific type of operations research problem, the best solution method could be different. This best solution method is selected through extensive numerical experiments [14,31]. Likewise, given different sets of input and output data, the best regression machine learning models should be tested. In this study, we test the effectiveness of the proposed framework by observing the VRP when solved using the GA.

In terms of computational time, it is shown that the prediction models could predict the objective values in a very short time (around 1 s). It is much shorter than the average time required to solve the VRP-GA for the largest-sized instance, which is around 1800 s (Table 1). We considered up to 700 customers in the numerical experiments, which was larger than the size of the real problem (e.g., 385 customers in [32]). This shows that the proposed method could deal with real-world problems effectively. It could be concluded that the proposed OpReMaL does not only predict the output of operations research problems well but also reduces the computational (prediction) time significantly. In the current big data era, it is strongly necessary to develop fast solution methods to ensure that good decisions are made based on recently collected data. It offers a huge opportunity to provide high-quality services and generate significantly larger profits for businesses and decision-makers.

In practice, the decision-makers simply need to run the prediction using regression machine learning when they need to observe the total traveled distances based on the given information of the VRP. However, when implementing the OpReMaL framework, it is necessary to understand when the prediction model needs to be tuned, which is when the characteristics of the VRP input differ from the ones considered before. The tuning starts with the addition of more input data by solving the VRP for the new data set using the GA, using the updated input data to tune the regression machine learning models and then selecting the best one for the new predictions.

6. Conclusions

This study proposed the Operations Research Problem Solving Using Machine Learning (OpReMaL) framework to predict the objective values of a vehicle routing problem. The proposed framework requires a very short time without running an operations research algorithm, which might require a long computational time, especially for large-sized problems. The proposed framework (1) differs from most frameworks that combine operations research and machine learning methods and (2) is the first one that considers regression machine learning models to observe the characteristics of the vehicle routing problem solved using the genetic algorithm. The numerical experiment's results showed that the best models for all sets of instances were random forest regression, the generalized linear model with a Poisson distribution, and ridge regression with cross-validation.

The proposed OpReMaL framework predicts the behavior of data that belong to a specific operations research problem and solution method. For future studies, it would be interesting to observe more operations research problems (e.g., the location routing problem [33], routing problem for shared logistics [34], electric vehicle relocation problem [14], multi-altitude drone routing problem for post-disaster observation [32]) and more solution methods (e.g., beetle swarm optimization [35], hybrid metaheuristics [36,37]) and show how the proposed OpReMaL framework could also obtain good solutions. It is challenging to determine the appropriate input data selection and observe how different the prediction result would be when different operations research solution methods are implemented to solve the problem. Future studies could also consider testing more advanced machine learning techniques, e.g., ensemble machine learning models [38]. Another possible implementation of the proposed method is in predicting the features of the best solutions instead of the objective. The issue to resolve is how to deal with the limited capability of machine learning models to predict only a single value, while the features of the best solutions are much more complicated than a single value. Such a problem needs a great deal of further investigation.

Author Contributions: Conceptualization, I.K.S. and M.L.S.; methodology, I.K.S.; software, I.K.S.; validation, I.K.S.; formal analysis, I.K.S.; resources, I.K.S.; data curation, I.K.S.; writing—original draft preparation, I.K.S.; writing—review and editing, I.K.S. and M.L.S.; visualization, I.K.S.; supervision, M.L.S.; project administration, I.K.S.; funding acquisition, I.K.S. and M.L.S. All authors have read and agreed to the published version of the manuscript.

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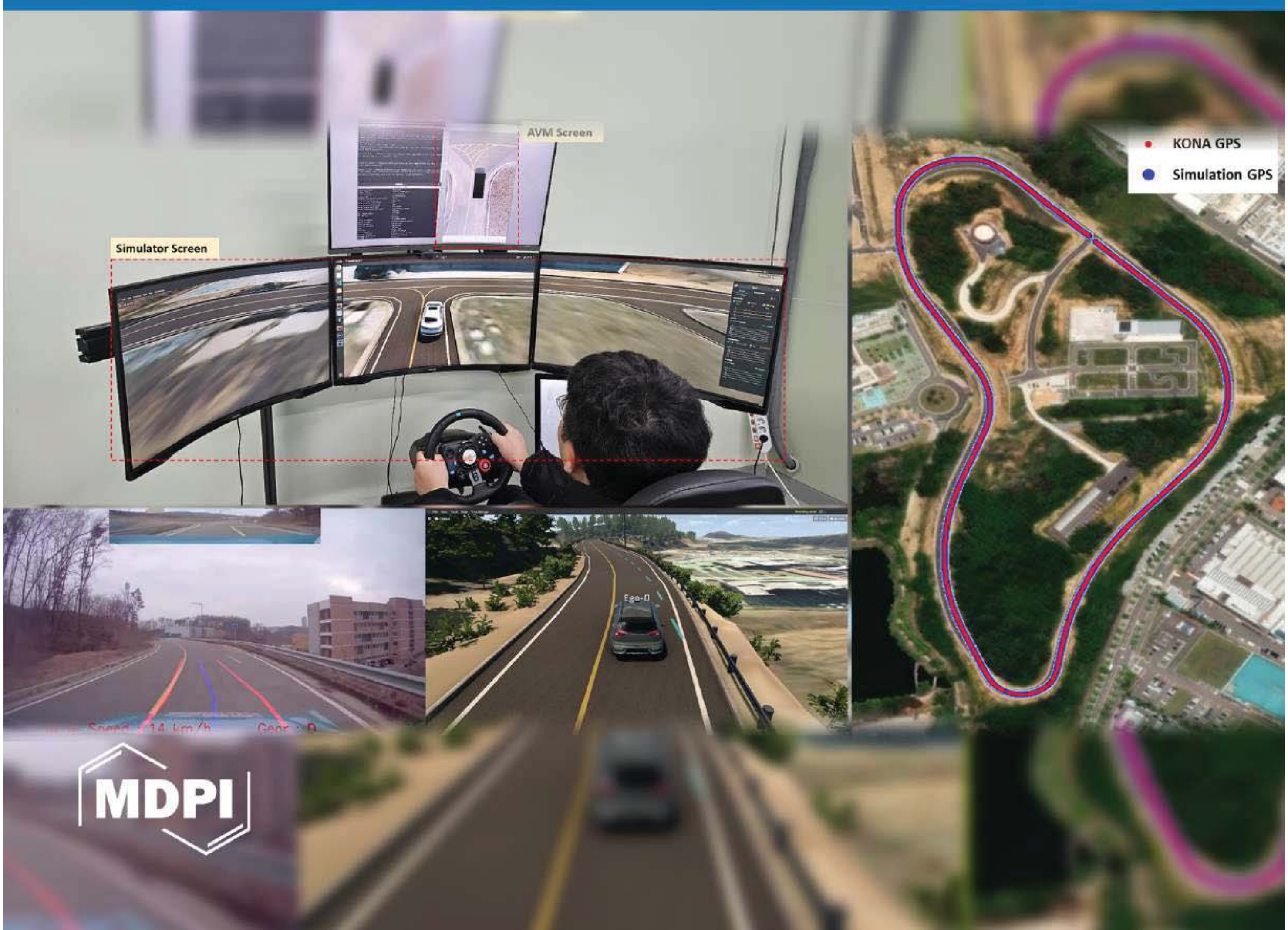
Teleoperated Driving with Virtual Twin Technology: A Simulator-Based Approach

Volume 15 · Issue 7 July 2024



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A Study on an Energy-Regenerative Braking Model Using Supercapacitors and DC Motors (/2032-6653/15/7/326)

by **Alistair Teasdale**, **Lucky Ishaku**, **Chiemela Victor Amaechi**, **Ibitoye Adelusi** and **Abdelrahman Abdelazim**

World Electr. Veh. J. **2024**, *15*(7), 326; **https://doi.org/10.3390/wevj15070326 (https://doi.org/10.3390/wevj15070326)** - 22 Jul 2024

Abstract This study presents an energy regeneration model and some theory required to construct a regeneration braking system. Due to the effects of carbon dioxide (CO_2) emissions, there is increasing interest in the use of electric vehicles (EVs), electric bikes, electric bicycles, **[...] Read more.**
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Shifting towards Electric Vehicles: A Case Study of Mercedes-Benz from the Perspective of Cross-Functional Teams and Workforce Transformation (/2032-6653/15/7/325)

by **Charisios Achillas** and **Parthena Iosifidou**

World Electr. Veh. J. **2024**, *15*(7), 325; https://doi.org/10.3390/wevj15070325 (https://doi.org/10.3390/wevj15070325) - 22 Jul 2024

Abstract The automotive industry's shift towards electric vehicles (EVs) is driven by technological advancements and environmental concerns. This paper examines Mercedes-Benz's strategy in this transition, highlighting the challenges and opportunities involved. Using thematic analysis of semi-structured interviews with key professionals at Mercedes-Benz, the study **[...] Read more.**

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Dynamic Charging Optimization Algorithm for Electric Vehicles to Mitigate Grid Power Peaks (/2032-6653/15/7/324)

by **Alain Aoun**, **Mehdi Adda**, **Adrian Ilinca**, **Mazen Ghandour** and **Hussein Ibrahim**

World Electr. Veh. J. **2024**, *15*(7), 324; https://doi.org/10.3390/wevj15070324 (https://doi.org/10.3390/wevj15070324) - 21 Jul 2024

Abstract The rapid proliferation of electric vehicles (EVs) presents both opportunities and challenges for the electrical grid. While EVs offer a promising avenue for reducing greenhouse gas emissions and dependence on fossil fuels, their uncoordinated charging behavior can strain grid infrastructure, thus creating new **[...] Read more.**

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Y...ADual: A Lightweight Traffic Sign Detection Model for a Mobile Driving System (/2032-6653/15/7/323)

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by Simin Fang, Chengming Chen, Zhijian Li, Meng Zhou and Renjie Wei
World Electr. Veh. J. **2024**, *15*(7), 323; https://doi.org/10.3390/wevj15070323 (https://doi.org/10.3390/wevj15070323) - 21 Jul 2024

Abstract Traffic sign detection plays a pivotal role in autonomous driving systems. The intricacy of the detection model necessitates high-performance hardware. Real-world traffic environments exhibit considerable variability and diversity, posing challenges for effective feature extraction by the model. Therefore, it is imperative to develop [...] Read more.
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Path Planning Algorithms for Smart Parking: Review and Prospects (/2032-6653/15/7/322)

by Zhonghai Han, Haotian Sun, Junfu Huang, Jiejie Xu, Yu Tang and Xintian Liu
World Electr. Veh. J. **2024**, *15*(7), 322; https://doi.org/10.3390/wevj15070322 (https://doi.org/10.3390/wevj15070322) - 20 Jul 2024

Abstract Path planning algorithms are crucial components in the process of smart parking. At present, there are many path planning algorithms designed for smart parking. A well-designed path planning algorithm has a significant impact on the efficiency of smart parking. Firstly, this paper comprehensively [...] Read more.
(This article belongs to the Special Issue Research on Intelligent Vehicle Path Planning Algorithm (/journal/wevj/special_issues/1O6T1QIXNE))

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Single-Snapshot Direction of Arrival Estimation for Vehicle-Mounted Millimeter-Wave Radar via Fast Deterministic Maximum Likelihood Algorithm (/2032-6653/15/7/321)

by Hong Liu, Han Xie, Zhen Wang, Xianling Wang and Donghang Chai
World Electr. Veh. J. **2024**, *15*(7), 321; https://doi.org/10.3390/wevj15070321 (https://doi.org/10.3390/wevj15070321) - 20 Jul 2024

Abstract As one of the fundamental vehicular perception technologies, millimeter-wave radar's accuracy in angle measurement affects the decision-making and control of vehicles. In order to enhance the accuracy and efficiency of the Direction of Arrival (DoA) estimation of radar systems, a super-resolution angle measurement **[...] Read more.**
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Dynamic Obstacle Avoidance for Mobile Robots Based on 2D Differential Euclidean Signed Distance Field Maps in Park Environment (/2032-6653/15/7/320)

by **Jingze Zhong**, **Mengjie Zhang**, **Zonghai Chen** and **Jikai Wang**

World Electr. Veh. J. **2024**, *15*(7), 320; **https://doi.org/10.3390/wevj15070320 (https://doi.org/10.3390/wevj15070320)** - 20 Jul 2024

Abstract In this paper, a novel and complete navigation system is proposed for mobile robots in a park environment, which can achieve safe and stable navigation as well as robust dynamic obstacle avoidance. The navigation system includes a global planning layer and a local **[...] Read more.**

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Development of a Low-Expansion and Low-Shrinkage Thermoset Injection Moulding Compound Tailored to Laminated Electrical Sheets (/2032-6653/15/7/319)

by **Florian Braunbeck**, **Florian Schönl**, **Timo Preußler**, **Hans-Christian Reuss**, **Martin Demleitner**, **Holger Ruckdäschel** and **Philipp Berendes**

World Electr. Veh. J. **2024**, *15*(7), 319; **https://doi.org/10.3390/wevj15070319 (https://doi.org/10.3390/wevj15070319)** - 18 Jul 2024

Abstract This study presents a thermoset moulding compound designed for electrical machines with high power densities. The compound reduces residual stresses induced by the difference in thermal expansion during use and by shrinkage in the compound during the manufacturing process. To reduce the internal **[...] Read more.**
(This article belongs to the Special Issue **Advances in Electrification and Thermal Management of Propulsion Systems (/journal/wevj/special_issues/0M6MCRR0X0)**)

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Open Access Article 19 pages, 3667 KiB (/2032-6653/15/7/318/pdf?version=1721374738)

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[The Impact of Consumer Sentiment on Sales of New Energy Vehicles: Evidence from Textual Analysis (/2032-6653/15/7/318)]

by **Yaqin Liu**, **Mengya Zhang**, **Xi Chen**, **Ke Li** and **Liwei Tang**

World Electr. Veh. J. **2024**, *15*(7), 318; https://doi.org/10.3390/wevj15070318 (https://doi.org/10.3390/wevj15070318) - 18 Jul 2024

Abstract The advancement of new energy vehicles (NEVs) represents a strategic initiative to combatting climate change, mitigating the energy crisis, and fostering green growth. Using provincial panel data from China between 2017 and 2022, in this study, we applied machine learning techniques for sentiment **[...] Read more.**

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[Optimizing Electric Racing Car Performance through Telemetry-Integrated Battery Charging: A Response Surface Analysis Approach (/2032-6653/15/7/317)]

by **A. F. Villa-Salazar**, **I. N. Gomez-Miranda**, **A. F. Romero-Maya**, **J. D. Velásquez-Gómez** and **K. Lemmel-Vélez**

World Electr. Veh. J. **2024**, *15*(7), 317; https://doi.org/10.3390/wevj15070317 (https://doi.org/10.3390/wevj15070317) - 18 Jul 2024

Abstract The link between the world of communications and the world of racing is provided by the telemetry systems in electric racing cars. These systems send real-time data about the vehicle's behavior and systems to enable informed decisions during the race. The objective of **[...] Read more.**

(This article belongs to the Special Issue **Lithium-Ion Batteries for Electric Vehicle (/journal/wevj/special_issues/LSWP1C7T7G)**)

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[Fractional Sliding Mode Observer Control Strategy for Three-Phase PWM Rectifier (/2032-6653/15/7/316)]

by **Tao Wang**, **Xin Li**, **Jihui Zhang**, **Shenhui Chen**, **Jinghao Ma** and **Cunhao Lin**

World Electr. Veh. J. **2024**, *15*(7), 316; https://doi.org/10.3390/wevj15070316 (https://doi.org/10.3390/wevj15070316) - 18 Jul 2024

Abstract This research presents a novel current loop control strategy for a three-phase PWM rectifier system aimed at mitigating challenges related to substandard power quality, excessive current harmonics, and insufficient robustness. The suggested approach combines an extended state observer (ESO) with dual-power sliding mode **[...] Read more.**

(This article belongs to the Special Issue **Intelligent Electric Vehicle Control, Testing and Evaluation (/journal/wevj/special_issues/Z8PJZ4KIO1)**)

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Study of an Electric Vehicle Charging Strategy Considering Split-Phase Voltage Quality (/2032-6653/15/7/315)

by **Fulu Yan**, **Mian Hua**, **Feng Zhao** and **Xuan Liang**

World Electr. Veh. J. **2024**, *15*(7), 315; https://doi.org/10.3390/wevj15070315 (https://doi.org/10.3390/wevj15070315) - 18 Jul 2024

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Abstract Slow-charging electric vehicle (EV) loads are single-phase loads in the power distribution network (PDN). The random access of these EVs to the network brings to the forefront the split-phase voltage quality issues. Therefore, a two-layer EV charging strategy considering split-phase voltage quality is **[...] Read more.**

(This article belongs to the Special Issue **Data Exchange between Vehicle and Power System for Optimal Charging (/journal/wevj/special_issues/Data_Exchange_Vehicle_Power_System_Optimal_Charging)**)

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Open Access Article 23 pages, 7194 KiB (/2032-6653/15/7/314/pdf?version=1721716183)

Energy Consumption Estimation Method of Battery Electric Buses Based on Real-World Driving Data (/2032-6653/15/7/314)

by **Peng Wang**, **Qiao Liu**, **Nan Xu**, **Yang Ou**, **Yi Wang**, **Zaiqiang Meng**, **Ning Liu**, **Jiyao Fu** and **Jincheng Li**

World Electr. Veh. J. **2024**, *15*(7), 314; https://doi.org/10.3390/wevj15070314 (https://doi.org/10.3390/wevj15070314) - 18 Jul 2024

Cited by 1 (/2032-6653/15/7/314#metrics) | Viewed by 1582

Abstract The estimation of energy consumption under real-world driving conditions is a prerequisite for optimizing bus scheduling and meeting the requirements of route operation, thereby promoting the large-scale application of battery electric buses. However, the limitation of data accuracy and the uncertainty of many **[...] Read more.**

(This article belongs to the Special Issue **Power and Energy Systems for E-mobility (/journal/wevj/special_issues/5LWLINH1Z3)**)

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Open Access Article 20 pages, 1075 KiB (/2032-6653/15/7/313/pdf?version=1721224864)

The Influence of Brand Greenwashing on EV Purchase Intention: The Moderating Role of Consumer Innovativeness and Peer Brand Attitude (/2032-6653/15/7/313)

by **Yuting Liao** and **Liang Wu**

World Electr. Veh. J. **2024**, *15*(7), 313; **https://doi.org/10.3390/wevj15070313 (https://doi.org/10.3390/wevj15070313)** - 17 Jul 2024

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Abstract In the context of new energy Electric Vehicles (EVs), certain car manufacturers engage in deceptive behaviors known as “greenwashing”, including activities such as “subsidy cheating”, “exaggerating carbon reduction claims”, and “selective disclosure of environmental information”. These behaviors have a negative impact on industry **[...] Read more.**

(This article belongs to the Special Issue **The Contribution of Electric Vehicles to Realization of Dual Carbon Goal (/journal/wevj/special_issues/IZ0ZC9K32N)**)

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Open Access Article 21 pages, 5003 KiB (/2032-6653/15/7/312/pdf?version=1721145836)

Analytical Calculation of Magnetic Field and Analysis of Rotor Permeability Effects on Permanent Magnet Synchronous Motor with Fractional Slot Concentrated Winding (/2032-6653/15/7/312)

by **Xuandong Wu**, **Huaiyuan Zhang**, **Cunxiang Yang** and **Hongbo Qiu**

World Electr. Veh. J. **2024**, *15*(7), 312; **https://doi.org/10.3390/wevj15070312 (https://doi.org/10.3390/wevj15070312)** - 16 Jul 2024

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Abstract Accurate calculation of the flux and the magnetic field distribution of fractional slot concentrated winding permanent magnet synchronous motor (FSCW PMSM) is the basis for motor performance analysis, and rapid calculation is key. In this paper, to solve the problem of difficult modeling **[...] Read more.**

(This article belongs to the Special Issue **Advanced Electrical Machine and Power Electronics for the Charging and Drive System of Electric Vehicles (EVs) (/journal/wevj/special_issues/M89NP49JN8)**)

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Open Access Editor’s Choice Article 14 pages, 10219 KiB (/2032-6653/15/7/311/pdf?version=1721128938)

Teleoperated Driving with Virtual Twin Technology: A Simulator-Based Approach (/2032-6653/15/7/311)

by **Keonil Kim** and **Seok-Cheol Kee**

World Electr. Veh. J. **2024**, *15*(7), 311; **https://doi.org/10.3390/wevj15070311 (https://doi.org/10.3390/wevj15070311)** - 16 Jul 2024

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Abstract This study introduces an innovative Teleoperated Driving (ToD) system integrated with virtual twin technology using the MORAI simulator. The system minimizes the need for extensive video data transmission by utilizing text-based vehicle information, significantly reducing the communication load. Key technical advancements include the **[...] Read more.**

(This article belongs to the Special Issue **EVS37—International Electric Vehicle Symposium and Exhibition (Seoul, Republic of Korea) (/journal/wevj/special_issues/0G8WT9LUEX)**)

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Open Access Editor's Choice Article 26 pages, 19864 KiB (/2032-6653/15/7/310/pdf?version=1721609484)

Evaluation of Vehicle Lateral and Longitudinal Dynamic Behavior of the New Package-Saving Multi-Link Torsion Axle (MLTA) for BEVs (/2032-6653/15/7/310)

by **Jens Olschewski** and **Xiangfan Fang**

World Electr. Veh. J. **2024**, *15*(7), 310; https://doi.org/10.3390/wevj15070310 (https://doi.org/10.3390/wevj15070310) - 15 Jul 2024

Abstract To increase the package space for the battery pack in the rear of battery electric vehicles (BEVs), and thus extend their driving range, a novel rear axle concept called the multi-link torsion axle (MLTA) has been developed. In this work, the kinematic design [...] Read more.

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Open Access Article 16 pages, 7052 KiB (/2032-6653/15/7/309/pdf?version=1720946867)

CCBA-NMS-YD: A Vehicle Pedestrian Detection and Tracking Method Based on Improved YOLOv7 and DeepSort (/2032-6653/15/7/309)

by **Zhenhao Yuan**, **Zhiwen Wang** and **Ruonan Zhang**

World Electr. Veh. J. **2024**, *15*(7), 309; https://doi.org/10.3390/wevj15070309 (https://doi.org/10.3390/wevj15070309) - 14 Jul 2024

Abstract In this paper, we propose a vehicle pedestrian detection and tracking method based on the improved YOLOv7 and DeepSort algorithms. We aim to improve the quality of vehicle pedestrian detection and tracking, addressing the challenges that current commercially available autonomous driving technologies face [...] Read more.

(This article belongs to the Special Issue **Advanced Vehicle Dynamics Identification, Control and Observer Methods for Autonomous, Electrified Vehicles (/journal/wevj/special_issues/7SH067L993)**)

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Open Access Article 15 pages, 1428 KiB (/2032-6653/15/7/308/pdf?version=1720922640)

Regression Machine Learning Models for the Short-Time Prediction of Genetic Algorithm Results in a Vehicle Routing Problem (/2032-6653/15/7/308)

by **Ivan Kristianto Singgih** and **Moses Laksono Singgih**

World Electr. Veh. J. **2024**, *15*(7), 308; **https://doi.org/10.3390/wevj15070308 (https://doi.org/10.3390/wevj15070308)** - 14 Jul 2024

Abstract Machine learning techniques have advanced rapidly, leading to better prediction accuracy within a short computational time. Such advancement encourages various novel applications, including in the field of operations research. This study introduces a novel way to utilize regression machine learning models to predict **[...] Read more.**

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Open Access Article 19 pages, 2503 KiB (/2032-6653/15/7/307/pdf?version=1721276581)

Real-Time Multimodal 3D Object Detection with Transformers (/2032-6653/15/7/307)

by **Hengsong Liu** and **Tongle Duan**

World Electr. Veh. J. **2024**, *15*(7), 307; **https://doi.org/10.3390/wevj15070307 (https://doi.org/10.3390/wevj15070307)** - 12 Jul 2024

Abstract The accuracy and real-time performance of 3D object detection are key factors limiting its widespread application. While cameras capture detailed color and texture features, they lack depth information compared to LiDAR. Multimodal detection combining both can improve results but incurs significant computational overhead, **[...] Read more.**

(This article belongs to the Special Issue **Advanced Vehicle Dynamics Identification, Control and Observer Methods for Autonomous, Electrified Vehicles (/journal/wevj/special_issues/7SH067L993)**)

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Open Access Article 15 pages, 2393 KiB (/2032-6653/15/7/306/pdf?version=1721645860)

Experimental Study on Structure Optimization and Dynamic Characteristics of Articulated Steering for Hydrogen Fuel Cell Engineering Vehicles (/2032-6653/15/7/306)

by **Qinguo Zhang**, **Xiaoyang Wang**, **Zheming Tong**, **Zhewu Cheng** and **Xiaojian Liu**

World Electr. Veh. J. **2024**, *15*(7), 306; **https://doi.org/10.3390/wevj15070306 (https://doi.org/10.3390/wevj15070306)** - 12 Jul 2024

Abstract The prominent problem of articulated steering structure of engineering vehicle is that there is pressure oscillation in the hydraulic system during steering, which seriously affects the performance of steering system. To solve this problem, the maximum stroke difference of left and right cylinders **[...] Read more.**

(This article belongs to the Special Issue **Advanced Vehicle Dynamics Identification, Control and Observer Methods for Autonomous, Electrified Vehicles (/journal/wevj/special_issues/7SH067L993)**)

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Open Access Article 13 pages, 231 KiB (/2032-6653/15/7/305/pdf?version=1720767235)

Distribution of the Burden of Proof in Autonomous Driving Tort Cases: Implications of the German Legislation for China (/2032-6653/15/7/305)

by **Zhihua Chen**, **Qianyi Cai** and **Hanbing Wei**

World Electr. Veh. J. **2024**, *15*(7), 305; https://doi.org/10.3390/wevj15070305 (https://doi.org/10.3390/wevj15070305) - 12 Jul 2024

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Abstract In the realm of autonomous driving tort, a significant disparity exists in the parties' access to autonomous driving data and essential technical information, resulting in challenges in unilateral proof. The traditional burden of proof framework in driving litigation is inadequate for direct application [...] Read more.

Open Access Article 18 pages, 294 KiB (/2032-6653/15/7/304/pdf?version=1720774887)

The Impact of R&D and Non-R&D Subsidies on Technological Innovation in Chinese Electric Vehicle Enterprises (/2032-6653/15/7/304)

by **Qiu Zhao**, **Zhuoqian Li** and **Chao Zhang**

World Electr. Veh. J. **2024**, *15*(7), 304; https://doi.org/10.3390/wevj15070304 (https://doi.org/10.3390/wevj15070304) - 11 Jul 2024

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Abstract The effectiveness of government subsidies for electric vehicle (EV) enterprises and future improvements to subsidy policies to promote industry development have garnered widespread attention. Distinct mechanisms exist through which R&D and non-R&D subsidies impact enterprise innovation. This paper differentiates between R&D and non-R&D [...] Read more.

(This article belongs to the Special Issue **Electric Vehicle Technology Development, Energy and Environmental Implications, and Decarbonization (/journal/wevj/special_issues/L43B3S0U2R)**)

Open Access Article 22 pages, 9953 KiB (/2032-6653/15/7/303/pdf?version=1720600382)

Development of an Improved Communication Control System for ATV Electric Vehicles Using MRS Developers Studio (/2032-6653/15/7/303)

by **Natthapon Donjaroennon**, **Wattana Nambunlue**, **Suphatchakan Nuchkum** and **Uthen Leeton**

World Electr. Veh. J. **2024**, *15*(7), 303; https://doi.org/10.3390/wevj15070303 (https://doi.org/10.3390/wevj15070303) - 9 Jul 2024

Viewed by 1817

Abstract Transmission, energy management, and distribution systems are critical components of modern electric vehicles, encompassing all sectors of the power system through communication control technology. One widely used communication system in electric vehicles is the Controller Area Network (CAN). This research aims to investigate [...] Read more.

(This article belongs to the Special Issue **Cooperative Perception, Communication and Computing for Autonomous Vehicles (/journal/wevj/special_issues/Y4L2FD3135)**)

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Open Access Article 22 pages, 10482 KiB (/2032-6653/15/7/302/pdf?version=1720513428)

Research on Experimental and Simulated Temperature Control Performance of Power Batteries Based on Composite Phase Change

Materials (/2032-6653/15/7/302)

by Yanchao Dong, Xiaozhong Ma, Chao Wang and Yuejuan Xu

World Electr. Veh. J. **2024**, *15*(7), 302; https://doi.org/10.3390/wevj15070302 (https://doi.org/10.3390/wevj15070302) - 9 Jul 2024

Abstract The power battery is a key component of electric vehicles and its performance is greatly affected by temperature. Battery thermal management systems based on phase change materials can effectively control the battery temperature and at the same time have the advantages of simple **[...] Read more.**

(This article belongs to the Topic **Advanced Battery Thermal Management Solution for Electric Vehicles (/topics/19QGRYZ8D9)**)

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Open Access Article 15 pages, 2429 KiB (/2032-6653/15/7/301/pdf?version=1720431279)

Consumer Segmentation and Market Analysis for Sustainable Marketing Strategy of Electric Vehicles in the Philippines (/2032-6653/15/7/301)

by **John Robin R. Uy**, **Ardvin Kester S. Ong**, **Danica Mariz B. De Guzman**, **Irish Tricia Dela Cruz** and **Juliana C. Dela Cruz**

World Electr. Veh. J. **2024**, *15*(7), 301; https://doi.org/10.3390/wevj15070301 (https://doi.org/10.3390/wevj15070301) - 8 Jul 2024

Abstract Despite the steady rise of electric vehicles (EVs) in other countries, the Philippines has yet to capitalize on its proliferation due to several mixed concerns. Status, socio-demographic characteristics, and availability have been the main concerns with purchasing EVs in the country. Consumer segmentation **[...] Read more.**

(This article belongs to the Special Issue **Deep Learning Applications for Electric Vehicles (/journal/wevj/special_issues/3756B1819W)**)

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An Obstacle Avoidance Trajectory Planning Methodology Based on Energy Minimization (OTPEM) for the Tilt-Wing eVTOL in the Takeoff Phase (/2032-6653/15/7/300)

by **Guangyu Zheng**, **Peng Li** and **Dongsu Wu**

World Electr. Veh. J. **2024**, *15*(7), 300; https://doi.org/10.3390/wevj15070300 (https://doi.org/10.3390/wevj15070300) - 6 Jul 2024

Abstract Electric tilt-wing flying cars are an efficient, economical, and environmentally friendly solution to urban traffic congestion and travel efficiency issues. This article addresses the high energy consumption and obstacle interference during the takeoff phase of the tilt-wing eVTOL (electric Vertical Takeoff and Landing), [...] Read more.

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Open Access Article 18 pages, 11712 KiB (/2032-6653/15/7/299/pdf?version=1721126484)

Ultra-Fast Nonlinear Model Predictive Control for Motion Control of Autonomous Light Motor Vehicles (/2032-6653/15/7/299)

by **Vaishali Patne**, **Pramod Ubare**, **Shreya Maggo**, **Manish Sahu**, **G. Srinivasa Rao**, **Deepak Ingole** and **Dayaram Sonawane**

World Electr. Veh. J. **2024**, *15*(7), 299; https://doi.org/10.3390/wevj15070299 (https://doi.org/10.3390/wevj15070299) - 4 Jul 2024

Abstract Advanced Driver Assistance System (ADAS) is the latest buzzword in the automotive industry aimed at reducing human errors and enhancing safety. In ADAS systems, the choice of control strategy is not straightforward due to the highly complex nonlinear dynamics, control objectives, and safety [...] Read more.

(This article belongs to the Special Issue **Advanced Vehicle System Dynamics and Control (/journal/wevj/special_issues/1D8Y7JEGOO)**)

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Open Access Article 19 pages, 3912 KiB (/2032-6653/15/7/298/pdf?version=1720746570)

Simple Method for Determining Loss Parameters of Electric Cars (/2032-6653/15/7/298)

by **Ansgar Wego** and **Stefan Schubotz**

World Electr. Veh. J. **2024**, *15*(7), 298; https://doi.org/10.3390/wevj15070298 (https://doi.org/10.3390/wevj15070298) - 3 Jul 2024

Abstract Manufacturers of electric cars provide their vehicles with many technical data that are important for the user. This includes information on dimensions, mass, performance, consumption, battery capacity, range, payload, etc. However, some interesting parameters are usually withheld from the end user. These parameters [...] Read more.

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Open Access Article 24 pages, 13355 KiB (/2032-6653/15/7/297/pdf?version=1720690841)

Enhanced Object Detection in Autonomous Vehicles through LiDAR—Camera Sensor Fusion (/2032-6653/15/7/297)

by **Zhongmou Dai**, **Zhiwei Guan**, **Qiang Chen**, **Yi Xu** and **Fengyi Sun**

World Electr. Veh. J. **2024**, *15*(7), 297; https://doi.org/10.3390/wevj15070297 (https://doi.org/10.3390/wevj15070297) - 3 Jul 2024

Abstract To realize accurate environment perception, which is the technological key to enabling autonomous vehicles to interact with their external environments, it is primarily necessary to solve the issues of object detection and tracking in the vehicle-movement process. Multi-sensor fusion has become an essential [...] Read more.

(This article belongs to the Special Issue Advanced Vehicle Dynamics Identification, Control and Observer Methods for Autonomous, Electrified Vehicles (/journal/wevj/special_issues/7SH067L993))

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Open Access Article 18 pages, 2392 KiB (/2032-6653/15/7/296/pdf?version=1720079057)

Robot Motion Planning Based on an Adaptive Slime Mold Algorithm and Motion Constraints (/2032-6653/15/7/296)

by **Rong Chen**, **Huashan Song**, **Ling Zheng** and **Bo Wang**

World Electr. Veh. J. **2024**, *15*(7), 296; https://doi.org/10.3390/wevj15070296 (https://doi.org/10.3390/wevj15070296) - 3 Jul 2024

Abstract The rapid advancement of artificial intelligence technology has significantly enhanced the intelligence of mobile robots, facilitating their widespread utilization in unmanned driving, smart home systems, and various other domains. As the scope, scale, and complexity of robot deployment continue to expand, there arises [...] Read more.

(This article belongs to the Special Issue Design Theory, Method and Control of Intelligent and Safe Vehicles (/journal/wevj/special_issues/CLXW68GJ97))

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[Research on a Path Tracking Control Strategy for Autonomous Vehicles Based on State Parameter Identification (/2032-6653/15/7/295)]

by **Dapai Shi**, **Fulin Chu**, **Qingling Cai**, **Zhanpeng Wang**, **Zhilong Lv** and **Jiaheng Wang**

World Electr. Veh. J. **2024**, *15*(7), 295; https://doi.org/10.3390/wevj15070295 (https://doi.org/10.3390/wevj15070295) - 2 Jul 2024

Abstract With the rapid development of autonomous driving technology, estimating and controlling key vehicle state parameters under complex road conditions have become critical challenges. This study combines Unscented Kalman Filtering (UKF) and Sliding Mode Control (SMC) methods to propose an integrated control model for [...] Read more.

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[Exploring the Relationship between Supply Chain Agility, Consumer and Electric Vehicle Characteristics, and Purchase Intentions in Thailand: A Structural Equation Modeling Approach (/2032-6653/15/7/294)]

by **Adisak Suvittawat**

World Electr. Veh. J. **2024**, *15*(7), 294; https://doi.org/10.3390/wevj15070294 (https://doi.org/10.3390/wevj15070294) - 2 Jul 2024

Abstract This research on electric vehicle purchasing intentions in Thailand using Structural Equation Modeling aimed to achieve the following objectives: Firstly, to investigate the factors influencing consumers' intentions to purchase electric vehicles. Secondly, to examine the impact of consumer characteristics on supply chain agility [...] Read more.

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[A Novel Robust H_∞ Control Approach Based on Vehicle Lateral Dynamics for Practical Path Tracking Applications (/2032-6653/15/7/293)]

by **Jie Wang**, **Baichao Wang**, **Congzhi Liu**, **Litong Zhang** and **Liang Li**

World Electr. Veh. J. **2024**, *15*(7), 293; https://doi.org/10.3390/wevj15070293 (https://doi.org/10.3390/wevj15070293) - 30 Jun 2024

Abstract This paper proposes a robust lateral control scheme for the path tracking of autonomous vehicles. Considering the discrepancies between the model parameters and the actual values of the vehicle and the fluctuation of parameters during driving, the norm-bounded uncertainty is utilized to deal [...] Read more.

(This article belongs to the Special Issue Dynamics, Control and Simulation of Electrified Vehicles (/journal/wevj/special_issues/9PVUB15XY6))

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Open Access Article 30 pages, 9113 KiB (/2032-6653/15/7/292/pdf?version=1719736053)

Research on Unmanned Vehicle Path Planning Based on the Fusion of an Improved Rapidly Exploring Random Tree Algorithm and an Improved Dynamic Window Approach Algorithm (/2032-6653/15/7/292)

by **Shuang Wang**, **Gang Li** and **Boju Liu**

World Electr. Veh. J. **2024**, *15*(7), 292; https://doi.org/10.3390/wevj15070292 (https://doi.org/10.3390/wevj15070292) - 30 Jun 2024

Abstract Aiming at the problem that the traditional rapidly exploring random tree (RRT) algorithm only considers the global path of unmanned vehicles in a static environment, which has the limitation of not being able to avoid unknown dynamic obstacles in real time, and that **[...] Read more.**

(This article belongs to the Special Issue **Research on Intelligent Vehicle Path Planning Algorithm (/journal/wevj/special_issues/1O6T1QIXNE))**

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Parametric Correlation Analysis between Equivalent Electric Circuit Model and Mechanistic Model Interpretation for Battery Internal Aging (/2032-6653/15/7/291)

by **Humberto Velasco-Arellano**, **Néstor Castillo-Magallanes**, **Nancy Visairo-Cruz**, **Ciro Alberto Núñez-Gutiérrez** and **Isabel Lázaro**

World Electr. Veh. J. **2024**, *15*(7), 291; https://doi.org/10.3390/wevj15070291 (https://doi.org/10.3390/wevj15070291) - 29 Jun 2024

Abstract In modern electric vehicle applications, understanding the evolution of the internal electrochemical reaction throughout the aging of batteries is as relevant as knowing their state of health. This article demonstrates the feasibility of correlating a mechanistic model of the battery internal electrochemical reactions **[...] Read more.**

(This article belongs to the Topic **Battery Design and Management (/topics/battery)**)

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Open Access Review 21 pages, 2507 KiB (/2032-6653/15/7/290/pdf?version=1720661385)

A Review of Key Technologies for Environment Sensing in Driverless Vehicles (/2032-6653/15/7/290)

by **Yuansheng Huo** and **Chengwei Zhang**

World Electr. Veh. J. **2024**, *15*(7), 290; https://doi.org/10.3390/wevj15070290 (https://doi.org/10.3390/wevj15070290) - 29 Jun 2024

Abstract Environment perception technology is the most important part of driverless technology, and driverless vehicles need to realize decision planning and control by virtue of perception feedback. This paper summarizes the most promising technology methods in the field of perception, namely visual perception technology, [...] Read more.

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Open Access Article 27 pages, 4090 KiB (/2032-6653/15/7/289/pdf?version=1721210728)

An Effective Strategy for Achieving Economic Reliability by Optimal Coordination of Hybrid Thermal–Wind–EV System in a Deregulated System (/2032-6653/15/7/289)

by **Ravindranadh Chowdary Vankina**, **Sadhan Gope**, **Subhojit Dawn**, **Ahmed Al Mansur** and **Taha Selim Ustun**

World Electr. Veh. J. **2024**, *15*(7), 289; https://doi.org/10.3390/wevj15070289 (https://doi.org/10.3390/wevj15070289) - 28 Jun 2024

Abstract This paper describes an effective operating strategy for electric vehicles (EVs) in a hybrid facility that leverages renewable energy sources. The method is to enhance the profit of the wind–thermal–EV hybrid plant while maintaining the grid frequency (f_{PG}) and energy level [...] Read more.
(This article belongs to the Special Issue **Data Exchange between Vehicle and Power System for Optimal Charging (/journal/wevj/special_issues/Data_Exchange_Vehicle_Power_System_Optimal_Charging)**)

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Open Access Article 19 pages, 9356 KiB (/2032-6653/15/7/288/pdf?version=1719893942)

Design of an Electric Vehicle Charging System Consisting of PV and Fuel Cell for Historical and Tourist Regions (/2032-6653/15/7/288)

by **Suleyman Emre Dagteke** and **Sencer Unal**

World Electr. Veh. J. **2024**, *15*(7), 288; https://doi.org/10.3390/wevj15070288 (https://doi.org/10.3390/wevj15070288) - 28 Jun 2024

Abstract One of the most important problems in the widespread use of electric vehicles is the lack of charging infrastructure. Especially in tourist

areas where historical buildings are located, the installation of a power grid for the installation of electric vehicle charging stations or [...] Read more.
(This article belongs to the Special Issue Electric Vehicle Technology Development, Energy and Environmental Implications, and Decarbonization (/journal/wevj/special_issues/L43B3S0U2R))

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Harmonic Resonance Mechanisms and Influencing Factors of Distributed Energy Grid-Connected Systems (/2032-6653/15/7/287)

by **Minrui Xu**, **Zhixin Li**, **Shufeng Lu**, **Tianyang Xu**, **Zhanqi Zhang** and **Xiangjun Quan**

World Electr. Veh. J. **2024**, *15*(7), 287; https://doi.org/10.3390/wevj15070287 (https://doi.org/10.3390/wevj15070287) - 26 Jun 2024

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Abstract With the rapid development of global energy transformation and new power system, ensuring the stability of distributed energy grid connections is the key to maintaining the reliable operation of the whole power system. This paper constructs detailed impedance models of grid-following (GFL) and [...] Read more.
(This article belongs to the Special Issue Active Voltage and Frequency Support Control by the EV, New Energy and Energy Storages (/journal/wevj/special_issues/9740A7Y475))

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Open Access Editor's Choice Review 31 pages, 2381 KiB (/2032-6653/15/7/286/pdf?version=1721120284)

A Comprehensive Review on Smart Electromobility Charging Infrastructure (/2032-6653/15/7/286)

by **Idowu Adetona Ayoade** and **Omowunmi Mary Longe**

World Electr. Veh. J. **2024**, *15*(7), 286; https://doi.org/10.3390/wevj15070286 (https://doi.org/10.3390/wevj15070286) - 26 Jun 2024

Cited by 4 (/2032-6653/15/7/286#metrics) | Viewed by 3540

Abstract This study thoroughly analyses Smart Electromobility Charging Infrastructure (SECI), exploring its multifaceted dimensions and advancements. Delving into the intricate landscape of SECI, the study critically evaluates existing technologies, integration methodologies, and

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emerging trends. Through a systematic examination of literature and empirical studies, the [...] Read more.
(This article belongs to the Special Issue Smart Charging Strategies for Plug-In Electric Vehicles (/journal/wevj/special_issues/J8693AX800))

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Open Access Article 19 pages, 8867 KiB (/2032-6653/15/7/285/pdf?version=1719395509)

CTM-YOLOv8n: A Lightweight Pedestrian Traffic-Sign Detection and Recognition Model with Advanced Optimization (/2032-6653/15/7/285)

by **Qiang Chen**, **Zhongmou Dai**, **Yi Xu** and **Yuezhen Gao**

World Electr. Veh. J. **2024**, *15*(7), 285; https://doi.org/10.3390/wevj15070285 (https://doi.org/10.3390/wevj15070285) - 26 Jun 2024

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Abstract Traffic-sign detection and recognition (TSDR) is crucial to avoiding harm to pedestrians, especially children, from intelligent connected vehicles and has become a research hotspot. However, due to motion blurring, partial occlusion, and smaller sign sizes, pedestrian TSDR faces increasingly significant challenges. To overcome [...] Read more.

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Factors Influencing the Adoption of Electric Jeepneys: A Philippine Perspective (/2032-6653/15/7/284)

by **Ma. Janice J. Gumasing**, **Elgene Dayne R. Ramos**, **Joshua Nathaniel C. Corpuz**, **Angelo James B. Ofianga**, **Juan Miguel R. Palad**, **Lyce Gariel B. Urbina**, **Mellicynt M. Mascariola** and **Ardvin Kester S. Ong**

World Electr. Veh. J. **2024**, *15*(7), 284; https://doi.org/10.3390/wevj15070284 (https://doi.org/10.3390/wevj15070284) - 26 Jun 2024

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Abstract The implementation of e-jeepneys stands as a change process that will eventually transition to the modernization of the public transport system in the Philippines. To address concerns about jeepneys' effects on the environment, energy use, society, the economy, and policies, their acceptability in [...] Read more.

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Open Access Editor's Choice Article 13 pages, 4221 KiB (/2032-6653/15/7/283/pdf?version=1719324476)

Design, Analysis, and Comparison of Electric Vehicle Drive Motor Rotors Using Injection-Molded Carbon-Fiber-Reinforced Plastics (/2032-6653/15/7/283)

by **Huai Cong Liu**, **Jang Soo Park** and **Il Hwan An**

World Electr. Veh. J. **2024**, *15*(7), 283; https://doi.org/10.3390/wevj15070283 (https://doi.org/10.3390/wevj15070283) - 25 Jun 2024

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Abstract Due to their excellent mechanical strength, corrosion resistance, and ease of processing, carbon fiber and carbon-fiber-reinforced plastics are finding wide application in diverse fields, including aerospace, industry, and automobiles. This research explores the feasibility of integrating

carbon-fiber solutions into the rotors of [...] Read more.
(This article belongs to the Special Issue Design and Control of Electrical Machines in Electric Vehicles, 2nd Edition (/journal/wevj/special_issues/Electrical_Machines_Electric_Vehicles_2nd_Edition))

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Impact of Temperature Variations on Torque Capacity in Shrink-Fit Junctions of Water-Jacketed Permanent Magnet Synchronous Motors (PMSMs) (/2032-6653/15/7/282)

by **David Sebastian Puma-Benavides**, **Luis Mixquititla-Casbis**, **Edilberto Antonio Llanes-Cedeño** and **Juan Carlos Jima-Matailo**
World Electr. Veh. J. **2024**, *15*(7), 282; https://doi.org/10.3390/wevj15070282 (https://doi.org/10.3390/wevj15070282) - 25 Jun 2024
Cited by 1 (/2032-6653/15/7/282#metrics) | Viewed by 1850

Abstract This study investigates the impact of temperature variations on the torque capacity of shrink-fit junctions in water-jacketed permanent magnet synchronous motors. Focusing on both baseline and improved designs; torque capacities were evaluated across a temperature range from −40 °C to 120 °C under [...] Read more.
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Motor Bearing Fault Diagnosis Based on Current Signal Using Time–Frequency Channel Attention (/2032-6653/15/7/281)

by **Zhiqiang Wang**, **Chao Guan**, **Shangru Shi**, **Guozheng Zhang** and **Xin Gu**
World Electr. Veh. J. **2024**, *15*(7), 281; https://doi.org/10.3390/wevj15070281 (https://doi.org/10.3390/wevj15070281) - 24 Jun 2024
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Abstract As they are the core components of the drive motor in electric vehicles, the accurate fault diagnosis of rolling bearings is the key to ensuring the safe operation of electric vehicles. At present, intelligent diagnostic methods based on current signals (CSs) are widely [...] Read more.

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Lithium-Ion Battery SOH Estimation Method Based on Multi-Feature and CNN-BiLSTM-MHA (/2032-6653/15/7/280)

by **Yujie Zhou**, **Chaolong Zhang**, **Xulong Zhang** and **Ziheng Zhou**

World Electr. Veh. J. **2024**, *15*(7), 280; https://doi.org/10.3390/wevj15070280 (https://doi.org/10.3390/wevj15070280) - 24 Jun 2024

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Abstract Electric vehicles can reduce the dependence on limited resources such as oil, which is conducive to the development of clean energy. An accurate battery state of health (SOH) is beneficial for the safety of electric vehicles. A multi-feature and Convolutional Neural Network–Bidirectional Long **[...] Read more.**

(This article belongs to the Special Issue **Intelligent Modelling & Simulation Technology of E-Mobility (/journal/wevj/special_issues/1VV3CT788Y)**)

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Open Access Article 14 pages, 4607 KiB (/2032-6653/15/7/279/pdf?version=1719368021)

Conceptual Design of an Unmanned Electrical Amphibious Vehicle for Ocean and Land Surveillance (/2032-6653/15/7/279)

by **Hugo Policarpo**, **João P. B. Lourenço**, **António M. Anastácio**, **Rui Parente**, **Francisco Rego**, **Daniel Silvestre**, **Frederico Afonso** and **Nuno M. M. Maia**

World Electr. Veh. J. **2024**, *15*(7), 279; https://doi.org/10.3390/wevj15070279 (https://doi.org/10.3390/wevj15070279) - 22 Jun 2024

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Abstract Unmanned vehicles (UVs) have become increasingly important in various scenarios of civil and military operations. The present work aims at the conceptual design of a modular Amphibious Unmanned Ground Vehicle (A-UGV) that can be easily adapted for different types of land and/or water **[...] Read more.**

(This article belongs to the Special Issue **Design Theory, Method and Control of Intelligent and Safe Vehicles (/journal/wevj/special_issues/CLXW68GJ97)**)

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Improvement of the Cybersecurity of the Satellite Internet of Vehicles through the Application of an Authentication Protocol Based on a Modular Error-Correction Code (/2032-6653/15/7/278)

by **Igor Anatolyevich Kalmykov**, **Aleksandr Anatolyevich Olenev**, **Natalya Vladimirovna Kononova**, **Tatyana Aleksandrovna Peleshenko**, **Daniil Vyacheslavovich Dukhovnyj**, **Nikita Konstantinovich Chistousov** and **Natalya Igorevna Kalmykova**

World Electr. Veh. J. **2024**, *15*(7), 278; https://doi.org/10.3390/wevj15070278 (https://doi.org/10.3390/wevj15070278) - 21 Jun 2024

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A Finite-Set Integral Sliding Modes Predictive Control for a Permanent Magnet Synchronous Motor Drive System (/2032-6653/15/7/277)

by **Hector Hidalgo**, **Rodolfo Orosco**, **Hector Huerta**, **Nimrod Vazquez**, **Leonel Estrada**, **Sergio Pinto** and **Angel de Castro**

World Electr. Veh. J. **2024**, *15*(7), 277; https://doi.org/10.3390/wevj15070277 (https://doi.org/10.3390/wevj15070277) - 21 Jun 2024

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Abstract Finite-set model predictive control (FS-MPC) is an easy and intuitive control technique. However, parametric uncertainties reduce the accuracy of the prediction. Classical MPC requires many calculations; therefore, the calculation time generates a considerable time delay in the actuation. This delay deteriorates the performance **[...] Read more.**

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Providing an Intelligent Frequency Control Method in a Microgrid Network in the Presence of Electric Vehicles (/2032-6653/15/7/276)

by **Mousa Alizadeh**, **Lilia Tightiz** and **Morteza Azimi Nasab**

World Electr. Veh. J. **2024**, *15*(7), 276; https://doi.org/10.3390/wevj15070276 (https://doi.org/10.3390/wevj15070276) - 21 Jun 2024

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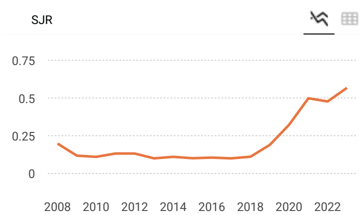

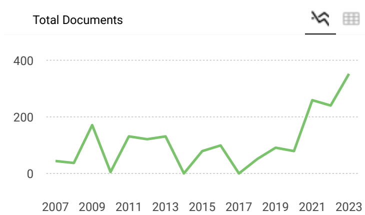

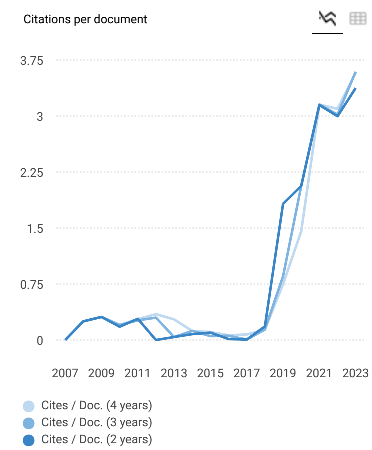

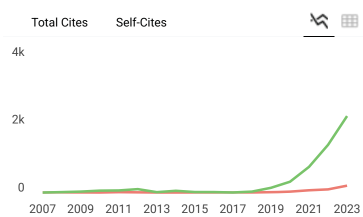

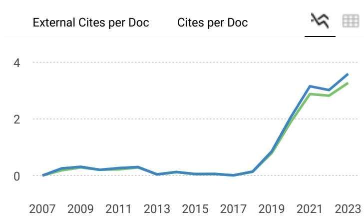

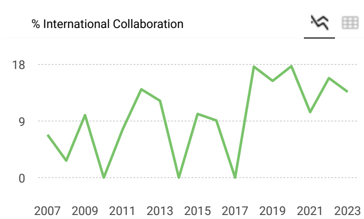

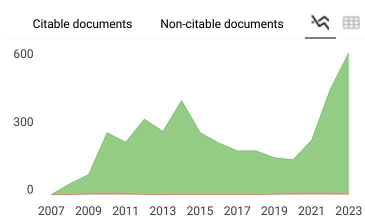

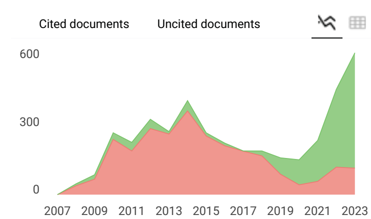

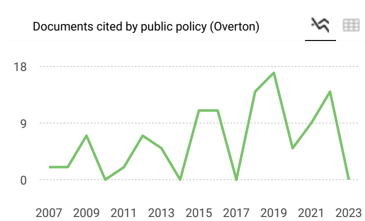

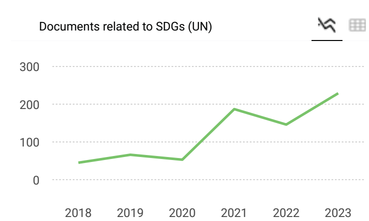

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