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Prediction of Diesel Engine Performance using Support Vector Regression Technique

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Abstract: ***Extensive research has been carried out on the prediction of diesel engine performance. Machine learning techniques such as support vector regression technique makes the performance predictions simpler. Support vector regression is a regression algorithm used to minimize the error with a threshold value and tries to fit the best line with a threshold value. In this paper, a detailed study of diesel engine performance using support vector regression and performance metrics such as brake thermal efficiency and accuracy are explored. Findings specify that support vector regression is an efficient technique for diesel engine performance that validates and compares the actual performance with high accuracy. For engine performance, the support vector machine supports to reduce the time and cost of testing.***

Keywords: Support Vector Regression, Engine Performance, Brake thermal efficiency.

I. INTRODUCTION

Engine performance characteristics are the critical parameters in evaluating an engine in terms of its efficiency and power output. Determining the performance characteristics of an engine is a prominent thing in the automobile industry. Many factors will affect the performance characteristics and, in turn, the engine's overall efficiency and power output. These testing procedures will consume a lot of resources and time.

A. Engine Performance Characteristics

The engine's performance mainly depends on the power; the torque developed, engine speed, and load. Fuel consumption is also taken into consideration to relate the engine performance with the economy of its usage. The efficiency of the engine is evaluated based on the purpose. To judge the engine performance by quantifying its capabilities such as Indicated Thermal Efficiency (η_{ith}), Brake Thermal Efficiency (η_{bth}), Mechanical efficiency (η_m) and Volumetric efficiency (η_v)

B. Parameters Affecting Engine Performance

1) Ambient Conditions

Both humidity and temperature will affect the engine's performance. When the humidity is high, and the temperature is low, the engine's performance will deteriorate. At higher altitudes, the engine performances can vary. An ambient pressure of 100kPa (1bar), the relative humidity of 30% and a temperature of 25°C is necessary for optimum performance per ISO 3046 conditions.

2) The Load

The engine's performance mainly depends on external load, the engine's speed, and throttle position. Generally, every engine's design is for a particular amount called rated load or maximum load at a specified speed. Wherever the engine's load increases, the engine speed decreases, to mitigate this loss in the engine speed, more fuel is necessary to the engine. When the load is more than the rated amount, we then treat that position as overloaded, in that position, speed decreases than the rated speed. In that condition, engine capacity to produce rotational power or torque comes down.

3) Emission Optimization

Generally, during the combustion process, pollutants get generated through engine performance. Nitrogen oxides form part of the most important pollutants. Generation of NOx is a combustion by-product, which is to exist. Environmental regulations will help us in reducing the contaminants. The two methods that are to minimize pollutants are primary and secondary methods. The primary method focuses on preventing the generation of NOx, whereas the second method focuses on the treatment of exhaust gas after its emission. Modern engines use both primary and secondary NOx reduction measures. Secondary methods do not affect the performance of an engine. The primary does affect the performance by optimizing the combustion and thus reducing the emissions.

4) Fuel Properties and Tolerance

Both fuel properties and driving conditions influence engine performance. Engines work with a wide range of fuel properties, but still, there are certain limitations. Fuels include the heating value or the methane number, which changes the engine efficiency. Based on ISO 3046 standard, the higher fuel consumption of +5% is necessary for specific fuel consumption declared at declared power.

C. Application of Machine Learning in Predictive Analysis

In recent years the Machine Learning has become a part of our human life without even knowing it. Machine learning is used in many ways in day to day events such as Stock market predictions, Weather forecast, Voice assistance, Face lock-in mobiles, suggestions in internet browsers, and many more.

Regression analysis is the first step in predictive analysis. The different types of regression models are widely popular in usage because they can easily be understood and implemented in any programming languages of our choice (Excel, R, Python, Minitab, KNIME - the list goes on and on). We have used MATLAB to implement the regression type in this paper.

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Machine Learning helps in developing a system that can learn from the past and perform the tasks. If we try to predict continuous data, then we will be using the regression model. One of the most commonly used regression algorithms is Linear Regression and Support Vector Regression. These algorithms exist by the application based on what the data analyst is predicting.

Support Vector Regression model is apt when there is a relationship between the dependent variable(s) (target) and the independent variable(s) (predictors). The Support Vector Regression model takes the predictor variables such as Brake thermal Efficiency of the engine, and target variables are speed, torque, fuel consumption, and power. Support Vector Regression algorithm will find out the relation between the predictor variables and the target variables.

II. LITERATURE SURVEY

In the year 1963, **Vladimir N. Vapnik** and **Alexey Ya. Cheronenkis** invented the Support vector regression algorithm. The standard algorithm we use at present has been proposed by **Corinna Cortes** and **Vapnik [1]** in 1993 and published in 1995. **Kongara Venkatesh, Sivanesan Murugesan [2]**, focused on predicting NOx and smoke emissions from a single-cylinder diesel engine using the Linear Regression Algorithm in Statistical Machine learning toolbox. Parameters like load and temperature were taken as input parameters to predict NOx and Smoke as output. The R squared error for NOx and smoke is 0.98 and 0.92, respectively. **Ayon Dey [3]** has discussed various machine learning algorithms apt for image processing, data mapping, and predictive analysis. Further discussed Decision tree, Naive Bayes, Support vector machine for Regression, Principle component analysis, K-means clustering, Generic modes, Self-training, Transductive Support vector machine, Reinforcement learning, Multi-task learning, Boosting, Bagging, Supervised neural network, Unsupervised Neural network, and Reinforced neural network. **Xianglong Luo, Danyang Li, and Shengrui Zhang [4]** have used hybrid predictive methodology by combining the discrete Fourier transforms with support vector regression. Between 2011 to 2015, data of real traffic conditions were collected from toll stations in Jiangsu province and used to estimate traffic flow. **Yufeng Li and Jinghui Xu [5]** have discussed the fuel quantity measurement from the fuel tank and the single-sensor measurement system. It can easily be implemented on board with a single-chip computer and has economic benefits. **Qingsong Zuo, Xinning Zhu, Zhiqiang Liu, Jianping Zhang, Gang Wu, and Yuelin Lib [6]** In this paper they have discussed the butanol-gasoline blends(0–60 vol %) and predicting the thermal brake efficiency, brake specific fuel consumption, and CO, UHC, NO_2, with different equivalence ratio. The root-mean-squared-errors of BTE, BSFC, CO, UHC, and NOx are 0.0511%, 4.6058 g/kW h, 0.9995% vol, 7.7503 ppm vol and 38.5861 ppm. **M Ghanbari, G Najafi1, B Ghobadian, R Mamat, M M Noor and A Moosavian [7]** In this they have discussed the prediction of the performance and exhaust emissions of a diesel engine with Carbon nanotubes and nanosilver particles with 40, 80 and 120 ppm blend with diesel fuel. With a gradual increase of nanoparticles from 40 to 120 ppm, CO_2 emissions have increased. CO emissions have decreased simultaneously with a rise in nanoparticles. UHC emissions have decreased with silver nano blend, whereas fuels that contain carbon nanoparticles increased. Using Support Vector Regression, they have predicted the engine performance and exhaust emissions with correlation coefficient and accuracy in range 0.66–1 and 65–99.5%. **Harsh S. Dhiman, Dipankar Deb, Josep M. Guerrero [8]** In this paper, they discuss various wind forecasting applications performances. The standard ε-SVR, LS-SVR, ε-Twin Support vector regression, and Twin Support vector regression. To evaluate the testing of dataset values collected from sites of the USA and India. Out of these, the hybrid model based on TSVR and ε-TSVR proved to be better forecasting. **Theodore B. Trafalis and Huseyin Ince [9]** In their paper, the comparison for Regression of Support vector regression with backpropagation and RBF networks. The training of data is through MATLAB.

III. METHODOLOGY

A. Experiment

This paper predicts the engine performance from a two-cylinder diesel engine. The test performed on a diesel engine coupled to a 50KW Eddy current dynamometer. Data acquisition systems are necessary to collect independent variables such as speed, torque, fuel consumption, and power.

B. Engine Specifications

The two-cylinder diesel engine, technical specifications of the diesel engine used in the experiment shown in Table I. below

TABLE I. TECHNICAL SPECIFICATIONS OF ENGINE

S.No	Parameter	Specification
1	Make	Mahindra Maximo
2	Engine Configuration	Two-Cylinder, Four Stroke
3	Type of Injection	Direct Injection
4	Type of Cooling	Air Cooled
5	Compression Ratio	18.5:1
6	Rated speed	3600 RPM
7	Maximum torque	55 Nm

C. Dynamometer Specifications

The dynamometer used in performing the test on the engine is Eddy Current Dynamometer, and its technical specifications are in Table II.

TABLE II. TECHNICAL SPECIFICATIONS OF DYNAMOMETER

S.No	Parameter	Specification
1.	Type	Eddy current dynamometer
2.	Capacity	50 kW

D. Testing and Acquiring Data

The two-cylinder diesel engine is attached to an Eddy current dynamometer to maintain the loads for the testing. All the rpm, fuel flow, and load cell sensors are in integrity into the data acquisition system and a monitor to collect and store the data. The experimental setup for engine emission testing is shown below in Fig. 1.

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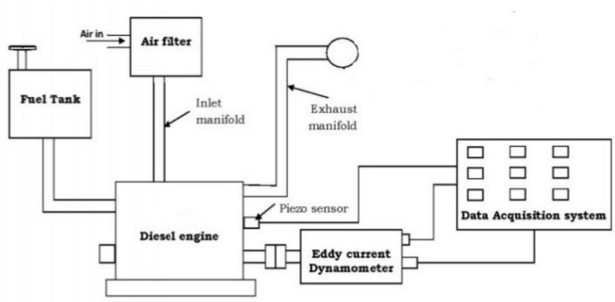

Fig. 1. Experimental Setup for Engine Emission Testing

IV. ALGORITHM AND TRAINING

A. Support Vector Regression

The support vector regression algorithm deals with labeled data, with a classification of supervised learning. We give real values to the system, so it comes under the regression type of problem. Support Vector Regression is a process of predicting the results by fitting a straight line in the data. In contrast, the other regression models reduce the error value between the actual and the predicted.

Mathematical Formulation of SVR

Support Vector Regression is a process of predicting the results by fitting a straight line in the data.

This algorithm consists of two types of data.

Independent variable 'x'

Dependent variable 'y.'

The independent variable 'x' does not have any dependency on other variables. However, the dependent variable 'y' is having a dependence on the independent variables, or the output will be changing.

This algorithm will fit a straight line into the data for the process of predictions using 'x' and 'y' data. The straight line is in the below form.

To find the linear function, we have an equation (1)

$$y = mx + c \qquad (1)$$

where

y = dependent or target variable

x = independent or predictor variable

m = slope of the straight line

c = 'y' intercept of the line

Similarly, the linear function

$$f(x)=x'\beta+b \qquad (2)$$

And the hyperplane should be flat as possible

We have to find f(x) with a minimal value ($\beta'\beta$).

$$J(\beta) = 1/2\beta'\beta \qquad (3)$$

Considering residual values less than ε; the equation (4) is

$$\forall n: |y-(x'\beta+b)| \le \varepsilon \qquad (4)$$

There is a possibility that to satisfy the constraints for all points, no such function f(x) exists

Introducing slack variables ξ and ξ* at each end of the margin.

These slack variables allow the regression errors to exist up to ξ and ξ* near the margin.

Slack variables will lead us to the objective function.

$$J(\beta) = 1/2\beta'\beta + CJ(\beta) = 1/2\,\beta'\beta + C\sum(\xi+\xi^*) \qquad (5)$$

Subject to equation

$\forall n: y-(x'\beta+b) \le \varepsilon+\xi$

$\forall n: (x'\beta+b)-y \le \varepsilon+\xi^*$

$\forall n: \xi^* \ge 0$

$\forall n: \xi \ge 0$

If observed values are within ε distance, the linear-insensitive loss function ignores errors by making them zero. To measure the loss with the help of the distance between predicted y and the ε boundary.

$$L\varepsilon = \begin{cases} 0 & \text{if } |y-f(x)| \le \varepsilon \\ |y-f(x)|-\varepsilon & \text{otherwise} \end{cases}$$

B. Importing Data

The data sets collected from the engine testing by varying the engine speed, obtaining the required data sets, and storing the data using the data acquisition system.

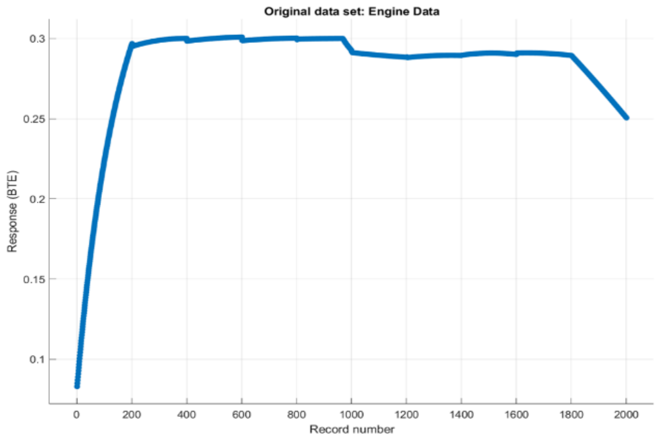

Fig. 2. Brake Thermal Efficiency data collected

Fig. 2. The graph describes the brake thermal efficiency at different speeds.

C. Training

Regression models try to minimize the difference between the predicted and the actual values. The training of data is necessary for the Regression Learner Application, which is a part of the Statistics and Machine Learning Toolbox in MATLAB. The data sets collected are imported in the regression Learners Application and are with an assignment to predictor and response variables. The toolbox provides all type of regression algorithms available in the machine learning and gives the freedom to select among them.

D. Types of Errors

The predicted results are evaluated based on errors between the actual values and predicted values. The regression learner application provides four different types of errors. The calculation of errors and the results are validated. Root Mean Square Error is the standard deviation of residuals (predicted errors). If the R-squared value is near to 1, then we have high efficiency in predicting. Hence, this error will show how far the data points are from the regression line. Mean Squared Error tells the deviation of the residuals. Mean Absolute Error measures the average vertical distance between the consecutive points and identity lines, and Absolute error is the difference between the actual and the predicted values.

The formulation of all these errors mentioned below.

Residual= actual value – predicted value

$$RMSE = \frac{\sqrt{\sum_{i=1}^{N}(actual - predicted)^2}}{N}$$

where N is the number of datasets gives

$$\text{Mean squared error} = \frac{1}{N}(actual - predicted)^2$$

$$\text{Absolute error} = |actual - predicted|$$

$$\text{Mean absolute error} = \frac{1}{N}|actual - predicted|$$

V. RESULTS

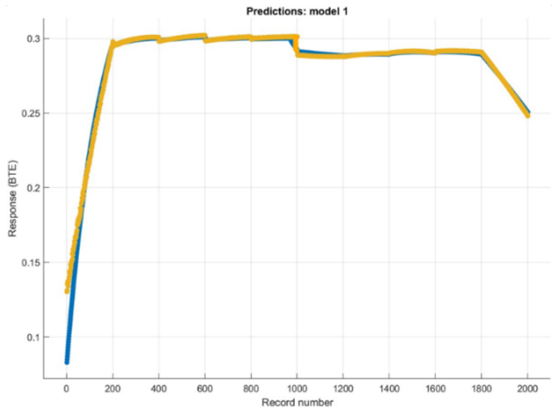

Fig. 3. Brake thermal Efficiency Response Plot

Fig. 3. The number of observations and Brake Thermal Efficiency is compared. The blue line represents the actual Brake thermal efficiency, and the yellow line on the chart represents the predicted observations (Brake thermal Efficiency) at different speeds.

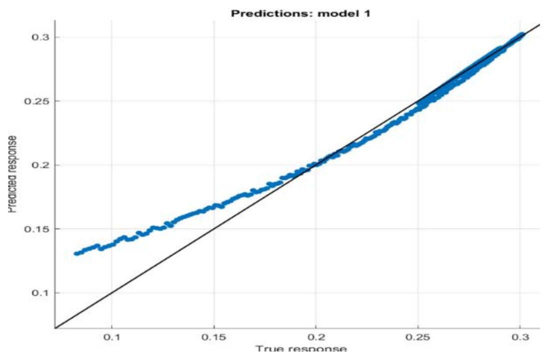

Fig. 4. Prediction vs. Actual Plot

The predicted observations near the fitted regression line is compared in Fig. 4, shows that the predicted points are less error as we measure the distance between points and the regression line.

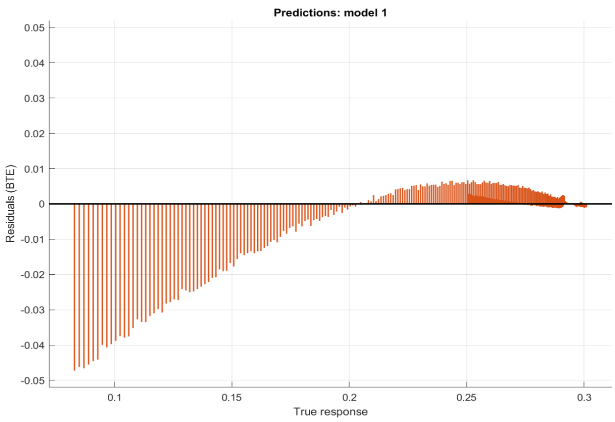

Fig. 5 BTE Residual Plot

Fig. 5. explains about how appropriate the model is for the data. If there is no pattern in the figure, the Regression which we choose is not correct.

The statistical results for predicting engine performance shown in Table IV.

TABLE III. STATISTICAL RESULTS

S. No	Error	Value
1.	RMSE	0.0048673
2.	RSE	0.98
3.	MSE	2.3691e-05
4.	MAE	0.0016327
5.	Training time	28.836 sec

Validation

The estimation of the engine performance of a diesel engine is with an accuracy of 98 %. The SVR technique which we choose is suitable for predicting engine performance.

TABLE IV. VALIDATED RESULTS

S.No	Actual BTE	Predicted BTE	Error %
1.	0.298	0.299	0.17
2.	0.300	0.3009	0.25
3.	0.289	0.2881	0.52
4.	0.288	0.289	0.21
5.	0.290	0.2907	0.08
6.	0.270	0.2713	0.28
7.	0.260	0.2616	0.35
8.	0.250	0.2516	0.40

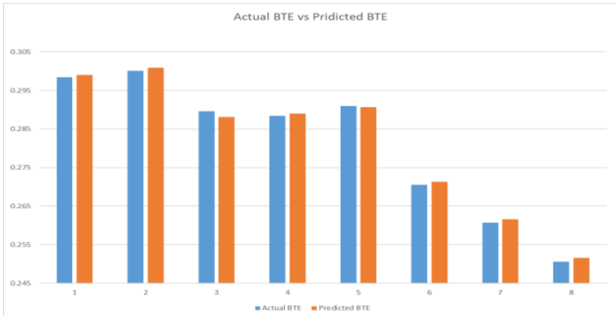

Fig. 6. Comparison plot

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A comparative plot between the actual brake thermal efficiency and the predicted brake thermal efficiency is shown in Fig. 6.

VI. CONCLUSION

The support vector Regression algorithm is appropriate and better in predicting engine performance. The data transformation and optimization techniques will help more in the prediction model to be accurate. The errors shown are acceptable with less training time and with R-Squared error as 0.98. Support vector regression, fitting of a straight line, can be practical if the datatype set is linear datatype. Using the Support Vector Regression algorithm, we can reduce the time and human effort involved in the testing engine performance.

REFERENCES

1. Corinna Cortes and Vapnik, "Support-Vector Networks" Machine Learning, 20, 273-297 (1995)
2. Kongara Venkatesh, Sivanesan Murugesan, "Prediction of Engine Emissions using Linear Regression Algorithm in Machine Learning" International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-9 Issue-7, May 2020
3. Ayon Dey, "Machine Learning Algorithms: A Review" International Journal of Computer Science and Information Technologies, Vol. 7 (3, 2016, 1174-1179).
4. Xianglong Luo, Danyang Li, and Shengrui Zhang. "Traffic Flow Prediction during the Holidays Based on DFT and SVR," Journal of Sensors, 2019.
5. Yufeng Li, and Jinghui Xu, "Multi-sensor Aviation Fuel Quantity Measurement Algorithm Based on SVR," AIP Conference Proceedings, 2122, 020060, 2019.
6. Qingsong Zuo, Xinning Zhu, Zhiqiang Liu, Jianping Zhang, Gang Wu, and Yuelin Lib, "Prediction of the performance and emissions of a spark-ignition engine fueled with butanol-gasoline based on support vector regression," Environmental American Institute of Chemical Engineers Journals, 2018.
7. M Ghanbari1, G Najafi1, B Ghobadian1, R Mamat, M M Noor and A Moosavian1, "Support vector machine to predict diesel engine performance and emission parameters fueled with nano-particles additive to diesel fuel," IOP Conf. Series: Materials Science and Engineering, 100 012069, 2015.
8. Harsh S. Dhiman, Dipankar Deb, Josep M. Guerrero, "Hybrid machine intelligent SVR variants for wind forecasting and ramp events," Renewable and Sustainable Energy Reviews 108, 369–379, 2019.
9. Theodore B. Trafalis and Huseyin Ince, "Support Vector Machine for Regression and Applications to Financial Forecasting," International Joint Conference on Neural Networks, 2000.
10. Sivanesan Murugesan. Lakshmikanthan Chinnasamy, Abhijeet Patil.," Developing & Simulating the Duty Cycle on Engine Dynamometer based on Engine RWUP, "SAE Technical Paper," 2015, 2015-26-0024.
11. Subramanian, R., et al. "Studies on Performance and Emission Characteristics of Multi-Cylinder Diesel Engine Using Hybrid Fuel Blends as Fuel," Journal of Scientific and Industrial Research, 2011.
12. Shaomin Wu, Artur Akbarov " Support Vector Regression for warranty claim forecasting," European Journal of Operational Research, 2011.
13. Srihari S., Dr. Thirumalini S., and Prashanth, K., "An experimental study on the performance and emission characteristics of PCCI-DI engine fuelled with diethyl ether-biodiesel-diesel blends," Renewable Energy, 2017, vol. 107, pp. 440 – 447.
14. Kadir Kavaklioglu, "Modeling and prediction of Turkey's electricity consumption using Support Vector Regression," Applied Energy, 2011.
15. Wei-Chiang Hong," Chaotic particle swarm optimization algorithm in a support vector regression electric load forecasting model," Energy Conversion and Management, 2009.
16. M N V R S S Sumanth and Sivanesan Murugesan, "Experimental Investigation of Wall Wetting Effect on Hydrocarbon Emission in Internal Combustion Engine," IOP Conf. Series: Materials Science and Engineering 577 (2019) 012029

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