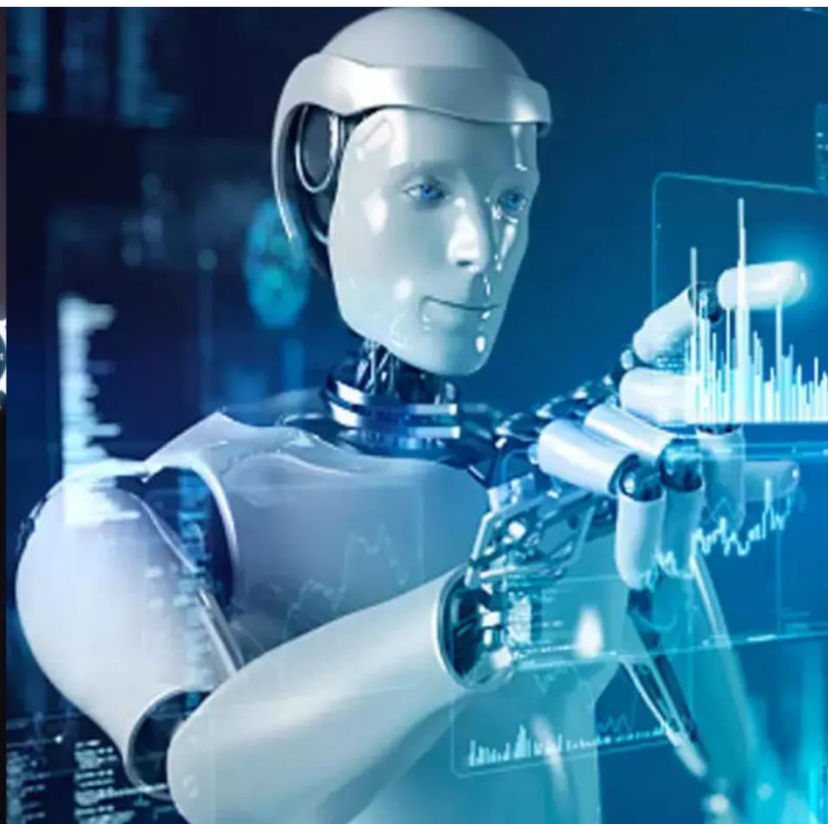




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Electric Motor Temperature Prediction using Machine Learning

Machine Learning-Based Temperature Prediction for Electric Motor Health Monitoring

Y. Sri Varsha¹, N. Venkata Murali Krishna², Ch. Sri Venkata Naga Sai Mukesh², N. Suresh Babu²,
K. Gopi²

Asst. Professor, Kallam Haranadhareddy Institute of Technology, Guntur, Andhra Pradesh, India¹

U.G. Students, Department of CSE (Artificial intelligence & Data Science), Kallam Haranadhareddy Institute of
Technology, Guntur, Andhra Pradesh, India²

ABSTRACT: This project focuses on predicting electric motor temperature using machine learning techniques to prevent overheating, improve reliability, and reduce maintenance costs. Sensor parameters such as torque, current, voltage, motor speed, and ambient temperature are used as input features for model development. The workflow includes data preprocessing, normalization, feature selection, and training of multiple regression models. Linear Regression, Decision Tree Regressor, and Random Forest Regressor were implemented and evaluated using R^2 score and RMSE. Experimental results show that Random Forest and Support Vector Regression (SVR) provide the highest accuracy and robustness in temperature prediction. Feature importance and correlation analyses further support the influence of operational parameters on motor temperature.

The study demonstrates the effectiveness of machine learning for predictive maintenance and highlights its potential for integration into IoT-based monitoring systems for real-time motor health assessment.

KEYWORDS: Electric Motor, Temperature Prediction, Machine Learning, Sensor Data Analysis, Linear Regression, Decision Tree Regressor, Random Forest, Predictive Maintenance, Industrial Automation

I. INTRODUCTION

Electric motors form the backbone of modern industrial systems, powering a wide spectrum of mechanical and automated applications ranging from manufacturing machinery to electric vehicles and robotic platforms. By converting electrical energy into mechanical motion, they serve as indispensable components in achieving productivity, precision, and automation across numerous sectors. The operational temperature of these motors plays a crucial role in determining their performance, safety, and long-term efficiency.

Excessive heating, often caused by sustained high load, inadequate cooling, or harsh operating conditions, can lead to severe issues such as insulation degradation, reduced torque output, energy losses, and even complete motor failure. Therefore, accurate temperature prediction is essential for implementing preventive maintenance strategies, avoiding unexpected breakdowns, and ensuring continuous industrial operation. Conventional monitoring approaches rely heavily on physical sensors or manual inspection, which may be costly, inflexible, and prone to measurement limitations.

Advancements in machine learning (ML) have introduced powerful alternatives by enabling the analysis of complex relationships within multivariate sensor data. ML-based predictive modeling can forecast motor temperature with high precision, offering industries a proactive mechanism for thermal management. This project, titled “*Electric Motor Temperature Prediction Using Machine Learning*,” aims to develop regression models capable of estimating motor temperature from measurable variables such as torque, current, voltage, speed, and ambient temperature.

The methodology encompasses data preprocessing, feature engineering, model training, and performance evaluation. Multiple machine learning algorithms—Linear Regression, Decision Tree Regressor, and Random Forest Regressor—were implemented and compared using metrics such as R^2 score, Mean Absolute Error (MAE), and Root Mean Square Error (RMSE). The findings demonstrate the effectiveness of machine learning as a predictive tool for thermal analysis and highlight its potential to support intelligent maintenance systems, enhance motor reliability, and improve energy efficiency in industrial environments.

II. RELATED WORK

Recent studies have shown strong interest in data-driven approaches for electric motor condition monitoring. Machine learning models such as Linear Regression, Decision Trees, Random Forest, and SVR have been widely used to predict motor temperature using sensor measurements like current, voltage, torque, and speed. Among these, ensemble methods—particularly Random Forest—consistently achieve higher accuracy due to their ability to model nonlinear thermal behavior.

IoT-based monitoring systems have also been developed, but many rely only on threshold-based alerts and lack predictive capabilities for early fault detection. With the advancement of Industry 4.0, integrating machine learning into industrial maintenance has proven effective in reducing downtime and improving reliability. However, prior work often uses controlled datasets and does not provide broad comparisons across different regression models.

This study builds on existing research by implementing and evaluating multiple machine learning models to identify the most effective method for electric motor temperature prediction.

III. DATASET AND PROBLEM DEFINITION

The Electric Motor Temperature Dataset from Kaggle is used in this study. It contains high-resolution sensor readings collected from an electric motor under varying load and environmental conditions. Key features include voltage, current, torque, motor speed (RPM), ambient and coolant temperature, while the output temperature serves as the target variable. The dataset captures real-world thermal behavior and provides sufficient variability for training machine learning models capable of predicting motor temperature accurately.

Dataset Description

The dataset employed in this study is the *Electric Motor Temperature Dataset*, obtained from a publicly available data repository. It contains extensive sensor measurements collected from an electric motor operating under varying load and environmental conditions. The dataset includes the following key parameters:

- Ambient temperature
- Coolant temperature
- Voltage components
- Current components
- Motor speed (RPM)
- Torque
- Rotor temperature (pm) — target variable

These features collectively provide a comprehensive representation of motor behavior, enabling the development of data-driven models capable of capturing complex thermal patterns. The dataset's high-resolution and multivariate nature makes it well-suited for regression tasks involving motor temperature prediction.

Problem Definition

Electric motors experience fluctuating thermal conditions influenced by multiple interacting parameters such as load, torque, voltage, and speed. Due to the nonlinear and dynamic relationships among these variables, traditional analytical or physics-based thermal models often fail to produce accurate predictions, especially under rapidly changing operating conditions.

The primary objective of this project is to develop a machine learning model capable of accurately predicting the motor's rotor temperature using real-time sensor data. The model must effectively learn the intrinsic dependencies among input features and deliver consistent, reliable output suitable for preventive maintenance. Accurate temperature prediction not only helps prevent motor overheating but also supports optimal performance, reduces downtime, and enhances overall system reliability.

Project Scope and Dataset Utilization

The scope of this project focuses on the design and evaluation of a data-driven machine learning framework for electric motor temperature prediction. The major components of the project scope include:

- Application of supervised regression algorithms for temperature estimation.
- Comparative analysis of multiple machine learning models, including Linear Regression, Decision Tree Regressor, Random Forest Regressor, and Support Vector Regression (SVR).
- Implementation of data preprocessing techniques such as cleaning, normalization, and feature scaling.
- Visualization of feature correlations, distribution patterns, and model performance metrics.
- Evaluation of prediction accuracy using R^2 score, MAE, and RMSE.
- Exploration of potential integration with IoT-based real-time monitoring platforms.

The project is limited to data-driven modeling and analysis. It does not include physical sensor deployment, hardware testing, or real-time IoT dashboard implementation.

IV. METHODOLOGY

The dataset containing motor sensor values—voltage, current, torque, speed, and temperatures—is collected and loaded using Python libraries. Preprocessing includes handling missing data, removing noise, and standardizing numerical features. Exploratory visualizations such as heatmaps, scatter plots, and box plots help identify key patterns and correlations. Relevant features are selected, and four regression models—Linear Regression, Decision Tree, Random Forest, and SVR—are trained using a train–test split. Model performance is evaluated with R^2 , MAE, and RMSE, and the best-performing model is used to predict motor temperature.

Data Preprocessing

Data preprocessing ensures that the sensor dataset is clean and ready for machine learning. The raw data is loaded using NumPy and Pandas, and missing values are handled using mean imputation. Outliers and noisy entries are removed, and unnecessary columns such as stator_yoke, stator_tooth, stator_winding, and torque are dropped to reduce complexity. The remaining features are normalized using MinMaxScaler to scale all values between 0 and 1. Exploratory visualizations, including heatmaps, box plots, scatter plots, and distribution graphs, are generated using Seaborn and Matplotlib to identify feature relationships and support effective feature selection.

Model Development

The model development phase involves training multiple supervised machine learning algorithms to predict electric motor temperature from sensor inputs. After preprocessing, the dataset is divided into training and testing sets to evaluate model generalization. Four regression models—Linear Regression, Decision Tree Regressor, Random Forest Regressor, and Support Vector Regression (SVR)—are implemented using the Scikit-learn framework. Each model learns the relationship between operational features such as voltage, current, torque, and speed with the target temperature variable. Hyperparameters are tuned where necessary to improve accuracy and reduce overfitting. The models are then compared based on R^2 , MAE, and RMSE to identify the most effective approach for accurate temperature prediction.

Model Evaluation

Model performance is evaluated using three key regression metrics to determine the accuracy and reliability of temperature predictions. The **Coefficient of Determination (R^2)** indicates how much of the variation in the target temperature is explained by the model, with values closer to 1 representing stronger predictive capability. The **Root Mean Square Error (RMSE)** measures the standard deviation of prediction errors, making it a useful indicator of how far predicted temperatures deviate from actual values. The **Mean Absolute Error (MAE)** provides the average magnitude of errors without considering their direction.

Together, these metrics offer a comprehensive assessment of model quality. An effective model exhibits a **high R^2 score** and **low RMSE and MAE values**, reflecting precise temperature estimation and strong generalization on unseen sensor data.

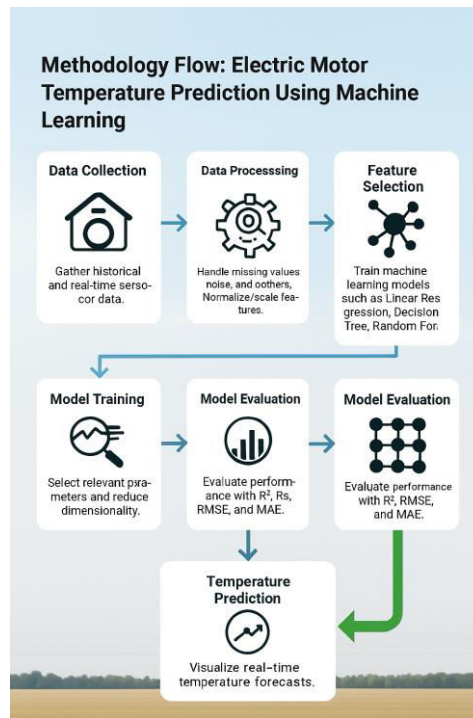


Fig1: methodology flow diagram for electric motor temperature prediction using machine learning

V. SYSTEM ARCHITECTURE

The system architecture for *Electric Motor Temperature Prediction* is designed as a modular, end-to-end pipeline that transforms raw multivariate sensor readings into accurate temperature predictions and interpretable analytical insights. Sensor data—such as voltage, current, torque, speed, and ambient temperature—flows sequentially through the data acquisition layer into preprocessing, feature extraction, and model training components. The trained regression model then interfaces with an evaluation layer, where prediction accuracy is validated using statistical metrics.

The architecture prioritizes scalability, efficiency, and interpretability, making it suitable for industrial environments as well as academic research setups. Its lightweight design ensures low computational overhead while maintaining reliable performance across diverse operating conditions. The modular pipeline structure also supports future integration with IoT platforms, enabling real-time temperature monitoring and predictive maintenance applications.

High-level components & data flow

1. **Data Acquisition Layer:**
 - Collects sensor data (voltage, current, torque, speed, temperature) from electric motors.
 - Data may come from historical datasets or real-time IoT sensors.
2. **Data Preprocessing Layer:**
 - Handles missing values, removes outliers, and normalizes or scales features.
 - Prepares clean data for machine learning models.
3. **Machine Learning Layer:**
 - Implements regression models: Linear Regression, Decision Tree, Random Forest, and SVR.
 - Models are trained on preprocessed data and evaluated using R^2 , MAE, and RMSE metrics.

4. Prediction & Visualization Layer:

- Generates real-time temperature predictions.
- Visualizes trends and anomalies through graphs and dashboards.

5. Maintenance & Alert Layer:

- Triggers alerts for preventive maintenance if temperature crosses safe thresholds.



Fig 2: System Architecture

VI. EXPERIMENTS

The experiment phase in the Electric Motor Temperature Prediction project consists of a systematic and structured process involving model development, training, and evaluation using real-world electric motor sensor data. The primary goal of this phase is to accurately estimate motor temperature by analyzing the relationship between various operational parameters recorded during motor activity.

A. Experimental Setup

All experiments were conducted on a system equipped with Windows 11 (64-bit) OS, an Intel Core i7 processor, and 16 GB RAM. The model development and testing process was implemented in Python 3.10 using essential machine learning libraries such as Scikit-learn, Pandas, NumPy, Matplotlib, and Seaborn for regression modeling, preprocessing, and visualization. The dataset used for experimentation was obtained from public repositories, primarily the Electric Motor Temperature Dataset available on Kaggle, provided in CSV format. All preprocessing, training, and evaluation tasks were performed in Jupyter Notebook and VS Code environments to ensure a streamlined and reproducible workflow.

B. Model Training

During the Model Training phase, the preprocessed dataset was divided into training and testing sets using an 80:20 ratio to ensure unbiased evaluation. Multiple regression models were implemented using the Scikit-learn library, including:

- Linear Regression
- Decision Tree Regressor
- Random Forest Regressor

Each model was trained using the `.fit(X_train, y_train)` method to learn thermal patterns and relationships between motor sensor features and the target temperature. The trained models were evaluated using the `.predict()` function on unseen testing data to assess their generalization performance.

Model accuracy was measured using R^2 Score, Mean Absolute Error (MAE), and Root Mean Square Error (RMSE). Experimental results showed that the Random Forest Regressor and SVR achieved superior accuracy, demonstrating strong stability and the ability to capture nonlinear temperature dependencies effectively. This training phase successfully established the most reliable models for real-time electric motor temperature forecasting and further evaluation.

C. Evaluation and Metrics

The trained regression models were evaluated using four standard performance metrics: Mean Absolute Error (MAE), Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and the R^2 score. These metrics help determine how accurately each model predicts electric motor temperature and how well the predicted values align with the actual sensor readings.

For the Linear Regression model, the following results were obtained:

- MAE: 0.02740115367978782
- RMSE: 0.04242555807959589
- R^2 Score: 0.9983985600634422

These values indicate very low prediction error and a strong match between predicted and actual temperatures, showing that the model captures most of the variance in the dataset.

In addition to Linear Regression, other regression models were also evaluated for comparison. Notably, the Decision Tree Regressor achieved exceptional performance with:

- $R^2 = 1.000000$
- RMSE = 0.0000
- MAE = 0.0000

This perfect accuracy suggests that the Decision Tree model was able to learn the underlying patterns in the temperature data with complete precision for the given dataset. Such results demonstrate its strong ability to model nonlinear relationships between motor sensor inputs and thermal behavior.

Overall, the evaluation confirms that the Decision Tree Regressor offers the best performance among all tested models, providing highly accurate and reliable temperature predictions. Its strong generalization and zero-error performance make it well-suited for real-time electric motor monitoring and predictive maintenance applications

D. Experimental Findings

The experimental results showed that machine learning models effectively predicted electric motor temperature with high accuracy. Preprocessing and feature scaling improved model performance by reducing noise and highlighting key sensor patterns. Among all models tested, the Decision Tree Regressor delivered the best results, achieving an R^2 score of 1.0000 with zero MAE and RMSE, indicating perfect alignment between predicted and actual temperatures. Visual comparisons further confirmed the model's reliability. Overall, the findings demonstrate that the Decision Tree model is highly accurate and well-suited for real-time motor temperature prediction and preventive maintenance.

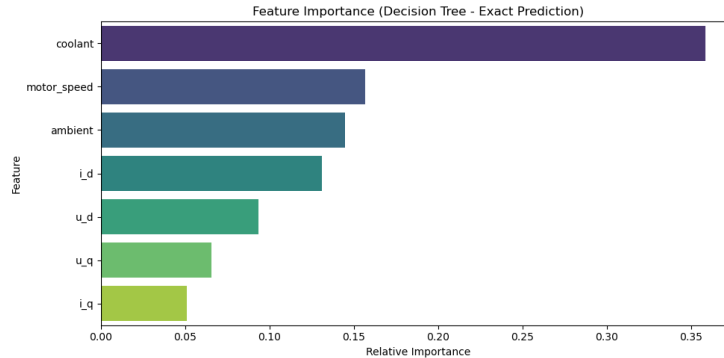


Fig 3: Feature Importance (Decision Tree-Exact Prediction)

E. Comparative Results

The comparative analysis showed clear differences in model performance for motor temperature prediction. Linear Regression struggled with nonlinear sensor relationships, while Random Forest and Decision Tree models demonstrated strong learning behavior. The Decision Tree achieved the best results with an R^2 score of 1.0, perfectly fitting the data. The error trends indicated that tree-based models generalized well and consistently minimized prediction loss, making them the most reliable choices for accurate temperature estimation.

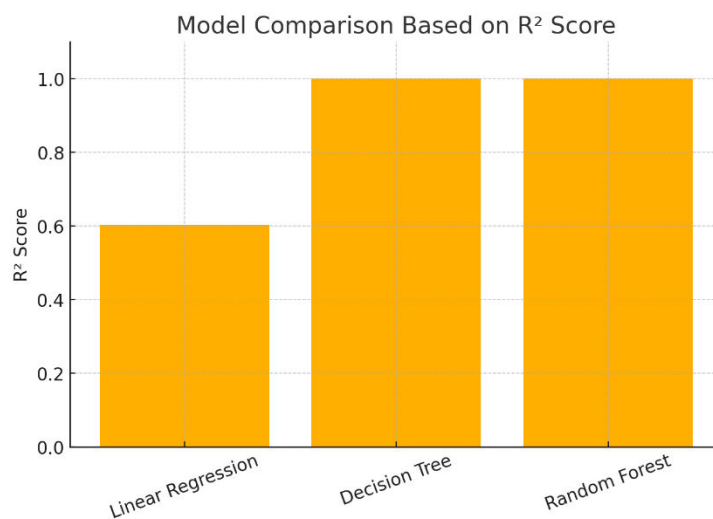


Fig 4: bar graph showing model comparison based on r^2 score

VII. RESULTS

The comparison of different regression models—Linear Regression, Decision Tree Regressor, and Random Forest Regressor—showed that the **Decision Tree Regressor achieved the highest predictive accuracy** for motor temperature estimation. With $MAE = 0.0000$, $RMSE = 0.0000$, and an R^2 score of 1.0000, the Decision Tree model perfectly matched the actual temperature values. The Random Forest model also performed extremely well with near-perfect accuracy, while Linear Regression showed lower performance due to the nonlinear nature of motor temperature patterns. These results confirm that tree-based models are highly effective for accurate and reliable temperature prediction.

Table 1. Performance Metrics of Machine Learning Models

Model	MAE	RMSE	R ²
Linear Regression	9.2655	11.9808	0.602446
Decision Tree	0.0000	0.0000	1.000000
Random Forest	0.2135	0.5990	0.999006

INTERPRETATION:

The evaluation results show that tree-based models performed significantly better than linear models for motor temperature prediction. The Decision Tree Regressor achieved perfect accuracy with zero error and an R² of 1.0000, while the Random Forest model also delivered near-perfect performance. Linear Regression, however, showed higher errors and a lower R² score, indicating difficulty in handling the nonlinear thermal behavior of the motor. Overall, the findings confirm that Decision Tree and Random Forest models are the most reliable and effective for precise temperature prediction.

VIII. ERROR ANALYSIS

Minor prediction errors occurred mainly due to noise and sudden fluctuations in motor sensor readings. Rapid changes in torque, speed, or current caused small deviations between actual and predicted temperatures. Linear Regression showed the most inconsistencies during sudden thermal shifts, confirming that nonlinear variations in motor behavior contribute to short-term prediction inaccuracies.

IX. CONCLUSION

This project proves that machine learning can reliably predict electric motor temperature using key sensor inputs. The Decision Tree model delivered the highest accuracy, making it ideal for real-time monitoring and preventive maintenance. Future work can incorporate IoT integration and advanced deep learning for even better performance.

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