Enhancing Temperature Forecasting of Blast Furnace Using Machine Learning & Deep Learning

A project report in the fulfillment of the Industrial Orientation Training in

IT & ERP DEPARTMENT, VISAKHAPATNAM STEEL PLANT

Submitted by

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(Duration: 5 June 2023 – 1 July 2023)

CERTIFICATE

This is to certify that the project work entitled "Enhancing Temperature Forecasting in Blast Furnace using Machine Learning and Deep Learning" is a record of work done by RAHUL ARYAN (Trainee No.: 100012927), student of Indian Institute of Technology, Hyderabad, in the fulfilment of the requirement for the completion of internship during the period 5 June 2023 to 1 July 2023 in IT & ERP Department, RINL-VSP.

Signature of Project guide

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DECLARATION

I hereby declare that this work entitled 'Enhancing Temperature Forecasting in Blast Furnace Using Machine Learning & Deep Learning' has been done under the guidance of Mr. T. V. Kameswara Rao (D.G.M). The work is original and has not been submitted to any university or college before fulfilling the requirements for any course of study or awarding any degree. The opinion is given, and the conclusions arrived at are of my own. The views expressed in the report do not represent the organization's views.

Sincerely

RAHUL ARYAN

ACKNOWLEDGEMENT

I take this opportunity to sincerely thank Mr. T. V. Kameswara Rao, D.G.M., IT & ERP Department, Visakhapatnam Steel Plant, for guiding me with his immense knowledge and helping in complete this project successfully.

I sincerely thank Mr. S. K. Mishra, GM I/C, IT & ERP Department, and Visakhapatnam Steel Plant, for investing his time in giving me an overview and helping me in completing the project successfully.

I wish to express my sincere thanks to the IT and ERP Department employees of Visakhapatnam Steel Plant for their valuable guidance in completing this project.

CONTENTS

ABSTRACT

A blast furnace (BF) is a giant counter-current reactor and heat exchanger and is the first step toward producing steel. The heart of the steel industry is the blast furnace because it creates molten pig iron, which is the primary ingredient in the production of steel. It is one of the most convoluted industrial reactors, which is impossible to model mathematically. A serious issue with industrial blast furnace is its operation and control. It is very important to minimize the operational cost, reduce fuel consumption, and optimize the overall efficiency of the blast furnace and also improve the productivity of the blast furnace. As a result, multiple deep learning algorithm configurations and machine learning algorithms are utilized to forecast and optimize various temperatures. Optimizing these temperature distributions would lead to substantial savings in the input material of the blast furnace. Regression models have been applied in this study to forecast and improve skin temperature. The input parameters used are Cold Blast Flow, Cold Blast Pressure, Cold Blast Temperature, Steam Flow, O2 Flow, O2 Percentage, Pulverized coal injection rate, Atmospheric Humidity, Hot Blast Temperature, Hot Blast Pressure, CO and CO, Content. Streamlit is used to implement the optimal algorithm and give an interactive user interface.

OVERVIEW OF VSP

RASHTRIYA ISPAT NIGAM LTD, (abbreviated as RINL), also known as Vizag Steel, is a public steel producer based in Visakhapatnam, India. RASHTRIYA ISPAT NIGAM LTD (RINL) is the corporate entity of Visakhapatnam Steel Plant (VSP), India's first shore-based integrated steel plant built with state-of-the-art technology. It is Founded in 1971, the plant focuses on producing value-added steel, producing 5.773 million tonnes of hot metal, 5.272 million tonnes of crude steel and 5.138 million tonnes of saleable steel.

Visakhapatnam Steel Plant (VSP) is a 7.3 MTPA plant. It was commissioned in 1992 with a capacity of 3.0 MTPA of liquid steel. The company subsequently completed its capacity expansion to 6.3 MTPA in April 2015 and to 7.3 MTPA in December 2017. The company is having one subsidiary, viz. Eastern Investment Limited (EIL) with 51% shareholding, which also have two subsidiaries, viz. M/s Orissa Mineral Development Company Ltd (OMDC) and M/s Bisra Stone Lime Company Ltd (BSLC). The company has a partnership in RINMOIL Ferro Alloys Private Limited and International Coal Ventures Limited in the form of Joint Ventures with 50% and 26.49% shareholding respectively.

The decision of the Government of India to set up an integrated steel plant at Visakhapatnam was announced by then Prime Minister Smt. Indira Gandhi in Parliament on 17 January 1971. VSP is the first coastal-based integrated steel plant in India, 16km west of the city of destiny, Vishakhapatnam, bestowed with modern technologies; VSP has an installed capacity of 3 million tons per annum of liquid steel and 2.656 million tons of saleable steel. The saleable steel here is in the form of wire rod coils, Structural, Special Steel, Rebar, Forged Rounds, etc.

At VSP, here lies emphasis on total automation, seamless integration and efficient upgradation. This result in a wide range of long and structural products to meet stringent demands of discerning customers in India & abroad; SP product meets exalting international Quality Standards such as JIS, DIN, BIS, BS, etc. RINL-VSP was awarded "Star Trading HOUSE" status during 1997-2000. Having established a fairly dependable export market, VSP Plans to make a continuous presence in the export market.

Different sections at the RINL VSP:

- Coke oven and coal chemicals plant
- Sinter plant
- Blast Furnace
- Steel Melt Shop
- Continuous casting machine
- Light and medium machine mills
- Calcining and refractive materials plant
- Rolling mills
- Thermal power plant
- Chemical power plant

INTRODUCTION

Blast Furnace is used from the very earliest days 1700B.C. around in Europe. The preparation of iron from the ancient to ending of medieval ages are same alternating layer of ore and wood were heated until molten ore was obtained. For the removing of impurities, the molten ore was hammered to get the raw iron which is complete forged. The metal was prepared a few away from the hearth. Initially easy tapering opening in the ground, the hearth evolved into a furnace, and was slowly perfect. In the early century's quantity of iron produced was few kilograms first then later its reached 55 to 65 kg at the medieval ages. From that period iron enriched with carbon steel were produced.

Inside the blast furnace a series of chemical and thermal reactions takes places. Many variables are involved as a process so as because of complexity exact mathematical process is difficult to model. In the present days many iron makers across the world wide used the modern technique to enhance the efficiency of the blast furnace by improving the quality of the molten iron.

In the blast furnace a very complex process takes place for the production of pig iron, which develops gradually as of the conventional furnace. A blast furnace melt downwards ore by the burning of the coke. Pig iron is produced as the output from the blast furnace by the series of several equations. The process of the blast furnace is very hard to replica as the coexistence of the phases with mass and heat transfer. The predicting of the outcome and controlling the blast furnace operations is very tough, operators are aware of this fact.

The production of the blast furnace is based on the temperature and pig iron chemical analysis. It also depends on the condition of the slag. These variables effect the output parameters in the operation of the blast furnace. So, we have to optimize the blast furnace parameters. We need a model that can automatically predict skin temperature. To predict the parameters so that operators can control the process efficiently. After then we will apply these predicted parameters to the genetic algorithm to optimize the predicted temperature.

Our task is to developed a predictive model first then optimize the predicted outcomes particularly with the help of regression models. For the developing these models we need the historical data of blast furnace. The data used in predicting the temperatures is real-time data. There are only some sets of system to track and it is extremely hard to forecast what type of model would employ fit for the known collection of data. In this present work we have trial several methods to minimize the root mean square value by training the data several time.

BACKGROUND

Blast Furnace

The steel plant's blast furnace is typically its most important component. Steel is made from molten iron as a raw material. The blast furnace generates molten iron, which is periodically tapped. Due to its low density, slag floats on top of the molten iron. Thus, the primary function of a blast furnace is to remove oxygen from iron oxides, resulting in the primary output being pig iron. For the reduction of iron ore, a tremendous quantity of heat is created in the blast furnace.

Limestone, iron ore, and coal are the three primary raw materials used in blast furnaces to create pig iron. The heat inside the blast furnace is produced using coke. To burn the coke, a hot blast is pumped through the tube level. This coke raises internal temperatures to a level necessary for iron ore reduction. The alternate layer of the blast furnace contains ore and coke. Coke serves as a reducing agent just like it does when used to reduce ore. Flux is used to clean impurities out of iron ore. Dolomite and limestone are utilized as a flux.

For producing pig iron first coke is produced. This is done by the process carbonization. For producing coke, coke oven is used. Coal is heated in coke oven. After the completion of the process coke has taken out from the oven. The main source of iron ore in BF is pellet which consists highly concentrated iron composition as oxides of iron. Sinter is the inferior iron source that is produced in plants.

Coke, sinter, pellets, and limestone are the most effective material processors before being sent to the plant in accordance with the BF charging concept. With the aid of air compressors and a stove system, oxygen is continuously pumped through tuyere nozzles into pressurized hot blast composition that has been heated to 1100- 1200°C. When coke is exposed to an extremely high-pressure blast, a combustion reaction occurs, raising the furnace's interior temperature to 2000–2500°C. By continuing to move and react with the carbon monoxide, the charge is to be oxidized. Carbon monoxide rises through the permeable bed during the reduction of the iron-bearing minerals. At a temperature of about 100°C, the partially oxidized gas eventually exits the process from the top of the blast furnace. The coke is oxidized to carbon monoxide in the lower zone of the furnace. The temperature in the furnace varies broadly: from few 100 -2000°C. Theoxygen is eliminated from the iron ore by the carbon monoxide gas. At the tuyere level the temperature is vary with 1600°C to 2100°C. At the shaft or stack zone the temperature is variesfrom 210 to 550°C and the exhaust gas which leaves out from the furnace known as uptake gas. The temperature carried with this gas is uptake gas temperature. Metal is tapped from the opening of the furnace at the irregular interval of time.

Machine Learning

A developing technology called machine learning makes it possible for computers to learn autonomously from historical data. Machine learning uses a variety of techniques to create mathematical models and make predictions based on previous information or data. Machine learning algorithms create a mathematical model with the aid of historical sample data, or "training data," that aids in making predictions or judgments without being explicitly programmed. Computer science and statistics are used with machine learning to create prediction models. Machine learning creates or employs algorithms that draw on past data. The performance will be higher the more information we supply. Libraries used:

NumPy

NumPy is a popular Python library for multi-dimensional array and matrix processing because it can be used to perform a great variety of mathematical operations. Its capability to handle linear algebra, Fourier transform, & more, makes NumPy ideal for ML and artificial intelligence (AI) projects, allowing users to manipulate the matrix to easily improve machine learning performance. NumPy is faster & easier to use than most other Python libraries.

Pandas

Pandas is another Python library that is built on top of NumPy, responsible for preparing high level data sets for machine learning and training. It relies on two types of data structures, one dimensional (series) and two-dimensional (Data Frame). This allows Pandas to be applicable in a variety of industries including finance, engineering, and statistics.

Seaborn

Seaborn is another open-source Python library, one that is based on Matplotlib (which focuses on plotting and data visualization) but features Pandas' data structures. Seaborn is often used in ML projects because it can generate plots of learning data. Of all the Python libraries, it produces the most aesthetically pleasing graphs and plots, making it an effective choice if you'll also use it for marketing and data analysis.

Matplotlib

Matplotlib is a Python library focused on data visualization and primarily used for creating beautiful graphs, plots, histograms, and bar charts. It is compatible for plotting data from SciPy, NumPy, and Pandas. If you have experience using other types of graphing tools, Matplotlib might be the most intuitive choice for you.

Scikit-learn

Scikit-learn is an open-source data analysis library and is the gold standard for Machine Learning(ML) in the Python ecosystem. Key concepts and features include: Algorithmic decision-making methods and Classification like identifying and categorizing data based on patterns.

Scikit-Optimize

Scikit-Optimize, or SKOPT, is a simple & efficient library to minimize expensive and noisy black-box functions. It implements several methods for sequential model-based optimization. SKOPT aims to be accessible and easy to use in many contexts. Scikit-Optimize provides support for tuning the hyperparameters of ML algorithms offered by the scikit-learn library, so-called hyperparameter optimization. The library is built on top of NumPy, SciPy and Scikit-Learn.

METHODOLOGY

To Predict the output parameters, we need to follow the standard machine learning workflow, which involves different phases that play a vital role in the development of the model. These stages include Data Collection, Data Preparation, Choosing Leaning Algorithm, Training Model, Evaluating Model, and Predicting the output.

INPUT PARAMETERS

O_2 Percentage:

In addition to the oxygen percentage in the atmosphere, an additional percentage of oxygen is sent to the blast furnace to increase the reduction process.

How does it affect the output parameters?

As the O_2 Percentage increases, the reduction process increases, and the top gas temperature also increases.

Carbon Monoxide (CO):

The iron ore is sent into the blast furnace from the top, and coke is also sent into the blast furnace for burning purposes. Due to the chemical reaction between coke and the iron ore, CO and CO2 are released.

How does it affect the output parameters?

The CO percentage can have a significant effect on the skin temperature and top gas temperature of the blast furnace.

A high CO percentage can indicate that the furnace is not operating efficiently and that the reaction temperature is too low, which can lead to low productivity. On the other hand, a low CO percentage can indicate that the furnace is producing more CO2, which can cause overheating and damage to the refractory lining.

Pulverized Coal Injection (PCI):

Generally, 1 ton of iron ore needs nearly 510 kg of coke for burning. This increases the cost of production. To decrease the cost of production, which is profitable for the company, we need to reduce the amount of coke needed per ton. For this purpose, the coal is ground and made into powder. This powder is sent into the blast furnace through a pipe so that the burning happens as usual and the coke percentage decreases. This reduces the cost of production. This process is called PCI.

How does it affect the Output parameters?

PCI have a positive effect on the skin temperature, as the injection of coal increases the energy release during combustion, leading to a higher skin temperature. This, in turn, can result in a higher top gas temperature, as the increased energy release affects the temperature of the gases that escape from the top of the furnace.

Top Pressure:

The "top pressure" in a blast furnace refers to the pressure at the top of the furnace, and it is an important parameter in the operation of the blast furnace. The top pressure affects several aspects of the blast furnace operation, including the skin temperature and top gas temperature of the furnace

How does it affect the Output Parameters?

The top pressure affects the skin temperature and top gas temperature of the furnace, and it must be maintained within the desired range to prevent overheating and damage to the refractory lining

O_2 Flow:

The amount of oxygen sent into the blast furnace for the reduction process is 02 flow. It is measured using a flow meter.

How does it affect the output parameters?

A high oxygen flow rate can also increase the top gas temperature, as more heat is generated and needs to be removed. If the top gas temperature becomes too high, it can lead to increased production

Steam flow:

The production cost should be reduced by reducing the amount of coke. The chemical formula for steam is H20. This H20 breaks into H2, which can be used to reduce the amount of coke. As steam flow increases, the number of coke decreases, thus decreasing production cost.

How does it affect the output parameters?

The effect of steam flow on the skin temperature and top gas temperature also depends on the specific conditions in the blast furnace. For example, the injection of steam can lead to a reduction in the carbon monoxide (CO) percentage, which can lower the skin temperature and top gas temperature.

Atmospheric Humidity:

Atmospheric humidity is the amount of water vapor carried in the air. It can be measured as vapor pressure, mixing ratio, or specific humidity. In summer, the humidity in the air increases, so we decrease the steam flow, whereas in winter, the humidity is less, increasing the steam flow.

How does it affect the output parameters?

When the ambient temperature is low, it can cause the skin temperature and top gas temperature in the blast furnace to decrease, as the energy release during combustion is reduced.

Cold Blast Pressure:

A stove in a blast furnace is a heat exchanger. The cool air is sent through an inlet into the blast furnace stove. This cool air gets heated due to the temperature of the blast furnace and produces hot air. The force with which this cold air is sent is the cold blast pressure.

How does it affect the output parameters?

If the cold blast pressure is too high, it can increase the skin temperature of the furnace, which can lead to overheating and damage to the refractory lining. If the cold blast pressure is too high, it can increase the top gas.

Cold Blast Temperature:

The temperature of the cold air that is sent into the inlet to the blast furnace is the cold blast temperature.

How does it affect the output parameters?

As the cold blast temperature increases, the temperature increases.

Hot Blast Pressure:

The cool air sent through an inlet into the blast furnace stove gets heated due to the of temperature the blast furnace and produces hot air. The force with which this hot air is released through the outlet of the blast furnace is the hot blast pressure.

How does it affect the output parameters?

As the hot blast pressure increases, the top gas temperature increases.

Hot Blast Temperature:

The temperature of the hot air that is sent into the inlet to the blast furnace is the hot blast temperature.

How does it affect the output parameters?

As the hot blast temperature increases, the top gas temperature increases.

Cold blast flow:

The amount of cold air sent through the inlet of the blast furnace is called cold blast flow.

How does it affect the output parameters?

As the cold blast flow increases, the top gas temperature increases.

Carbon Dioxide (CO_2):

The iron ore is sent into the blast furnace from the top, and coke is also sent into the blast furnace for burning purposes. Due to the chemical reaction between coke and the iron ore, CO and CO_2 are released.

How does it affect the output parameters?

The skin temperature is influenced by the CO_2 percentage because $C0_2$ acts as an oxidizing agent, promoting the combustion of carbon monoxide (CO), which is produced during the reduction of iron oxides The top gas temperature is also influenced by the CO_2 percentage because $C0_2$ is a product of combustion and its concentration in the top gas directly affects the energy release during combustion. A higher $C0_2$ percentage in the top gas indicates a higher energy release and thus a higher top gas temperature.

H_2(Hydrogen):

The hydrogen (H_2) percentage in the blast furnace affects the skin temperature.

How does it affect the Output Parameters?

A higher H_2 percentage in the top gas indicates a higher energy release and thus a higher top gas temperature The skin temperature is influenced by the H_2 percentage because H_2 acts as a reducing agent, reducing iron oxides to metallic iron. The higher the H_2 percentage, the more efficiently the iron oxides are reduced, leading to higher skin temperatures.

OUTPUT PARAMETERS: (**Skin temperature Average)**

A shell is present around the blast furnace where we maintain the skin temperatures at particular points. Here we predicted the average skin temperatures. Skin temperatures are maintained for a healthy furnace. A refractory layer around the blast furnace protects it from damage. If the skin temperatures increase abnormally, the refractory layer gets damaged, resulting in leakage from the blast furnace, which is dangerous. So, the skin temperatures should be maintained to protect the refractory lining.

Data Collection

The data is collected from the Vizag steel plant (VSP) for five months (01-07-2021 to 31-12 2021) at an interval of 10 minutes. The collected information has 25406 rows, and 25 columns contain various missing values and other errors.

Data Preparation

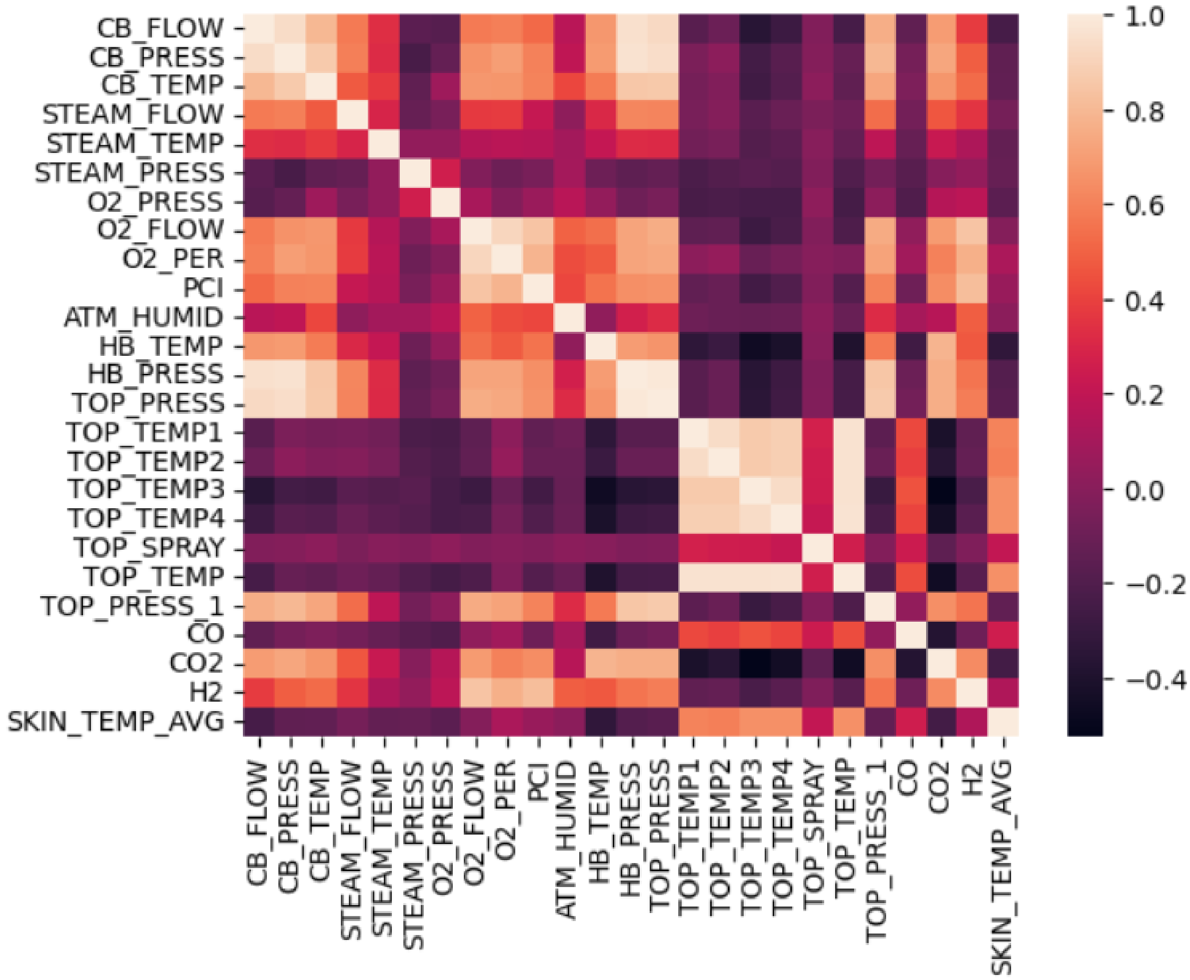
The parameters were analyzed, and the crucial input and output parameters were selected based on a correlation matrix between the parameters. The wrangled data enables us to predict the output after distinct intervals (the data collected had these parameters instantaneously described). So, the final data consists of 21486 rows, 18 columns (for l hour interval); 21475 rows ,18 columns (for 3- hour interval) and 21454 rows,18 columns (for 6-hour interval).

Correlation Matrix

A correlation matrix enables us to determine if a feature within a dataset correlates positively or negatively with other features, as well as how well or poorly they do so. An illustration of a correlation matrix that shows the relationship between various variables is called a correlation heatmap.

The value of correlation can take any value from -1 to 1.

Correlation between two random variables or bivariate data does not necessarily imply a causal relationship.



Choosing the learning algorithm:

We utilize supervised learning methods since the data in this case has been labeled. Additionally, as the output parameters are continuous variables, we forecast them using regression approaches. To acquire the optimum outcome from each of them, machine learning techniques like Multiple Linear Regression, Random Forest Regression, and Neural Networks are applied. The training and evaluation phases are as follows:

1. For each of the learning algorithms, we have split the data into 70% training and 30% testing data respectively.
2. The evaluation metric is the R2 Score which is defined as:

$$R^2 = 1 - \frac{RSS}{TSS}$$

where RSS & TSS represent Residual and Total Sum of Squares. The higher the value, the better the result.

3. Also, the database is modified in order to predict the skin temperature values over the next 4 hours when other parameters along with current skin temperature are given.

MULTIPLE LINEAR REGRESSION:

Multiple Linear Regression is a statistical modelling technique used to explore the relationship between a dependent variable and multiple independent variables. The idea of simple linear regression is expanded by using many predictors to build a more complete model. The objective of this method is to estimate the coefficients that represent the influence of each predictor on the dependent variable. It is assumed that the relationship between the dependent variable and each independent variable is linear. The error distribution and variance are both assumed to be normal by the model.

RANDOM FOREST REGRESSION:

Random Forest Regression is a popular machine learning algorithm that leverages the power of ensemble learning and decision trees for regression tasks. It combines multiple individual decision trees to create a robust and accurate predictive model. The algorithm works by building a multitude of decision trees on randomly selected subsets of the training data. Each decision tree independently makes predictions, and the final prediction is obtained by averaging or taking the majority vote of the individual tree predictions. Random Forest Regression handles non-linear relationships, interactions, and outliers effectively. It also addresses the issues of overfitting and high variance often encountered with decision trees.

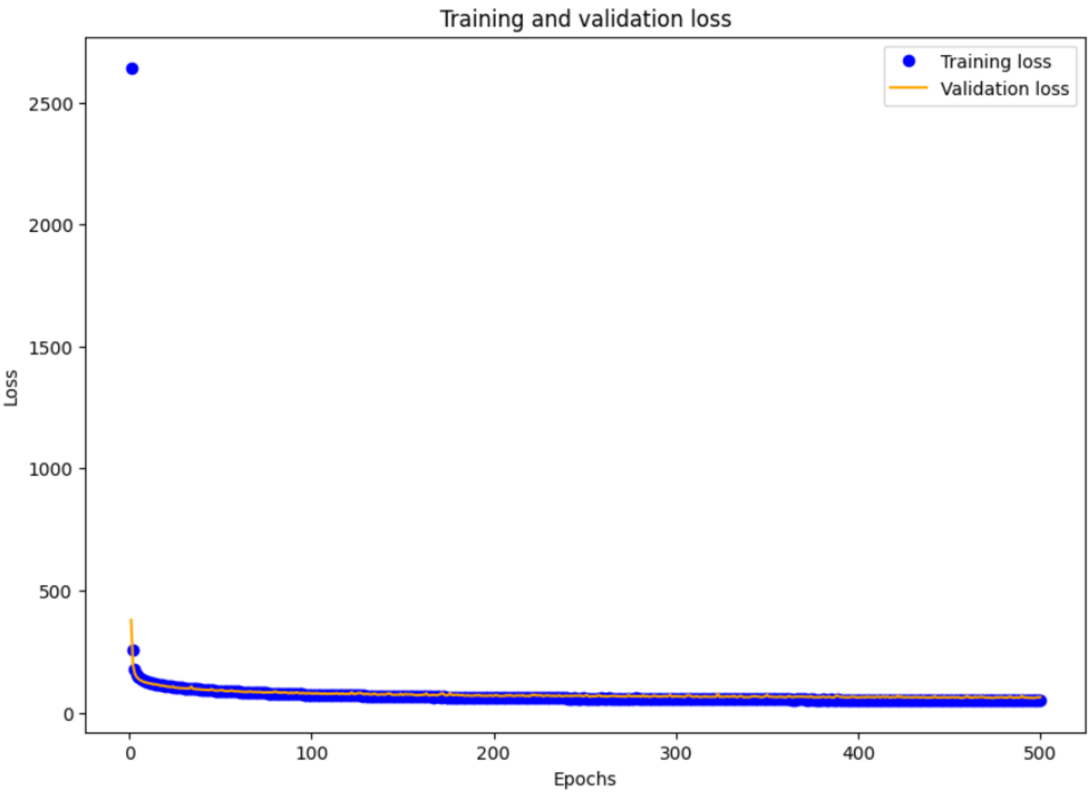
DEEP NEURAL NETWORKS:

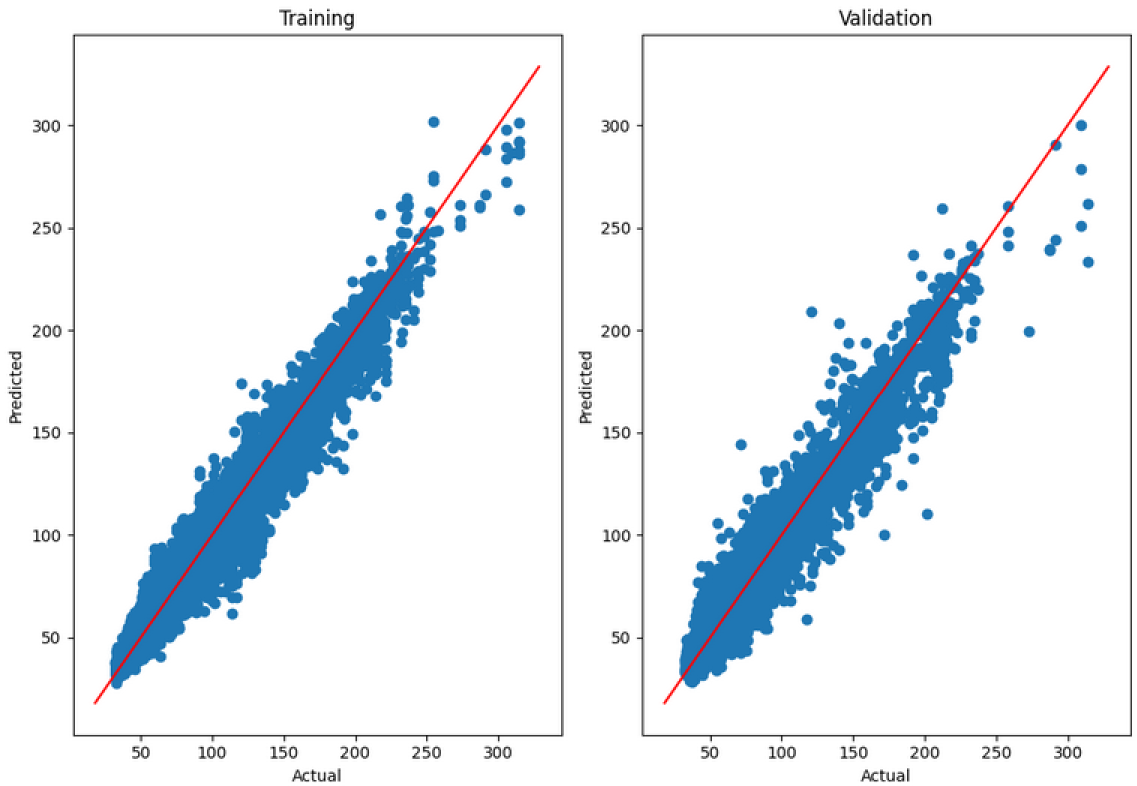
Regression using Deep Neural Networks (DNN) is a powerful technique that applies the principles of deep learning to regression problems. DNNs are made up of many layers of connected nodes (neurons) that can learn to represent the input data hierarchically. When performing regression tasks, the network's output layer makes continuous predictions based on the input data. Deep Neural Networks are well suited for a variety of regression issues because they can recognize intricate patterns and non-linear relationships in the data. DNNs may learn and extract useful features from the input data, enabling them to make precise predictions. These techniques include convolutional layers, recurrent layers, and dense layers. Optimizing a loss function during DNN training sometimes includes using techniques like stochastic gradient descent and backpropagation.

What is done in the project?

I have used all of the above 3 models by using several different parameters and doing hyper parameter tuning to achieve the best R2 score and deploy the best model for usage.

Below are the results of loss values across various epochs and comparison b/w actual and predicted values for the best possible deep neural network:





RESULTS:

The results for the best R2 scores for the above 3 learning algorithms under different parameters of training is given in the below table:

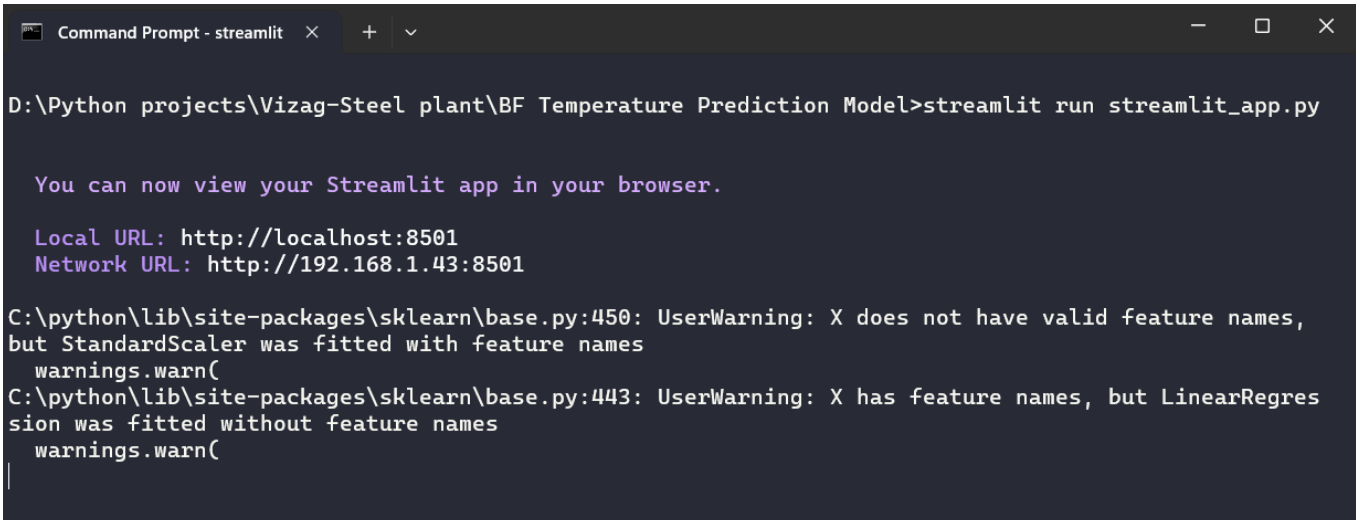
MODEL	R2 SCORE (max = 1)
Multiple Linear Regression	0.8143
Multiple Linear Regression (with PCA: 12 components)	0.8096
Multiple Linear Regression (with PCA: 20 components)	0.8138
Random Forest Regressor (n_estimators=100, max_depth=50)	0.9475
Random Forest Regressor (n_estimators=400, max_depth=100)	0.9481
DNN (25 - 100 - 50 - 25 - 4) → 3 hidden layers	0.9225
DNN (25 - 128 - 32 - 8 - 4) → 3 hidden layers	0.9095
DNN (25 - 100 - 75 - 50 - 25 - 4) → 4 hidden layers	0.9312
DNN (25 - 128 - 64 - 32 - 16 - 8 - 4) → 5 hidden layers	0.9382

MODEL DEPLOYMENT

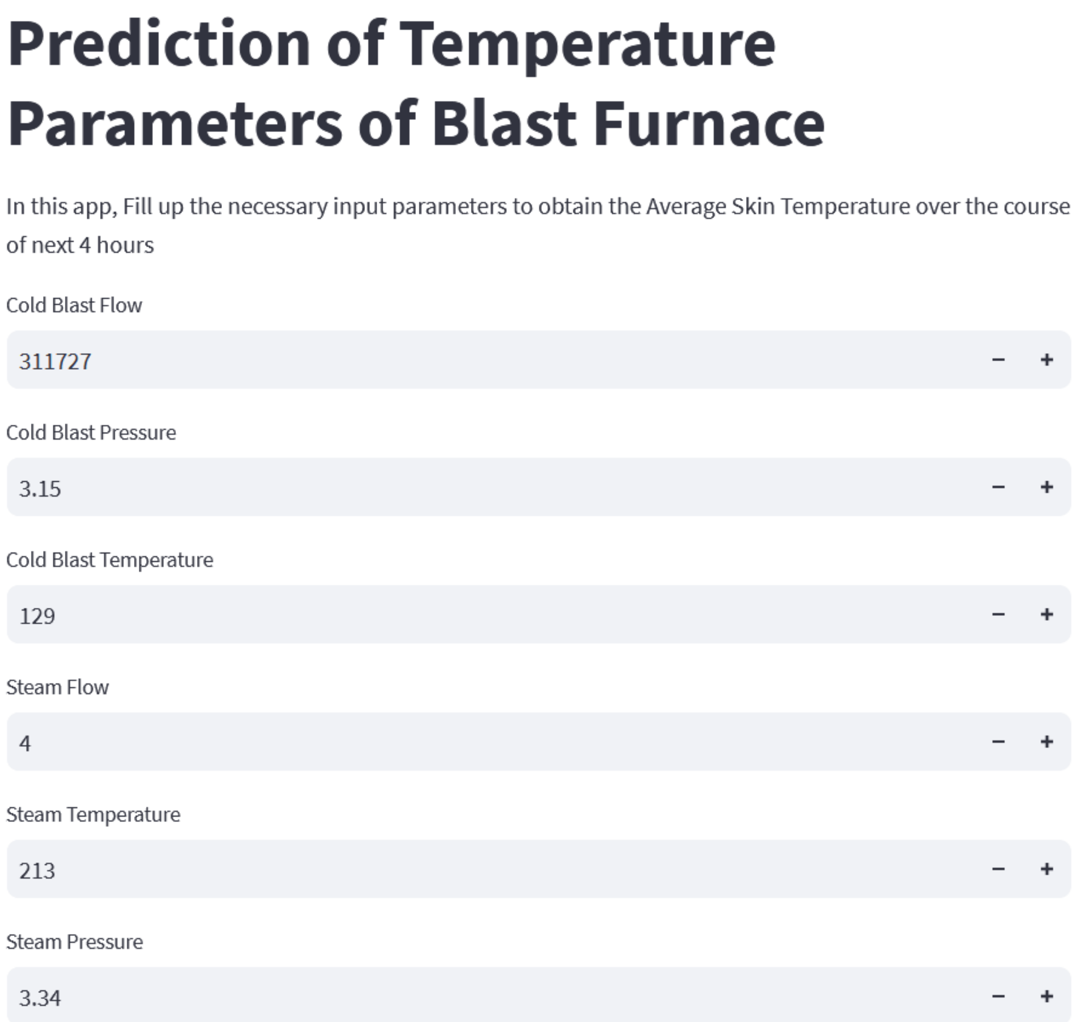
Deployment of the model is essential as it allows the user to interact with the model. This interactive front-end implementation is achieved using Streamlit.

Streamlit is a free and open-source framework that enables us to create an interface using python only. It is used to quickly create and distribute stunning data science and machine learning web apps. This Python-based library was created with machine learning engineers in mind. Since they are not web developers, data scientists or machine learning engineers are not interested in spending weeks learning how to use these frameworks to create online applications. They prefer a tool that is simpler to learn and use, as long as it can display data and gather the modeling-related factors. With just a few lines of code, you can use stream light to produce an application that looks great.

Here is the command to deploy the webpage Streamlit run streamlit_app.py after setting the path using cd file location:



<u>**An App featuring input values to be fed to predict the following outcome:**</u>



O2 Pressure

3.20 − +

O2 Flow

7296 − +

O2 Percentage

23.08 − +

Pulverized Coal Injection

32 − +

Atmospheric Humdity

24.56 − +

Hot Blast Temperature

1060 − +

Hot Blast Pressure

2.99 − +

Top Gas Pressure

1.50 − +

Top Gas Temperature after 10 minutes

112

Top Gas Temperature after 20 minutes

135

Top Gas Temperature after 30 minutes

107

Top Gas Temperature after 40 minutes

130

Top Gas Spray

0

Top Gas Temperature

121

Top Gas Pressure 1

2

CO (carbon monoxide)

22.22

CO2 (carbon dioxide)

21

H2 (Hydrogen)

3.88

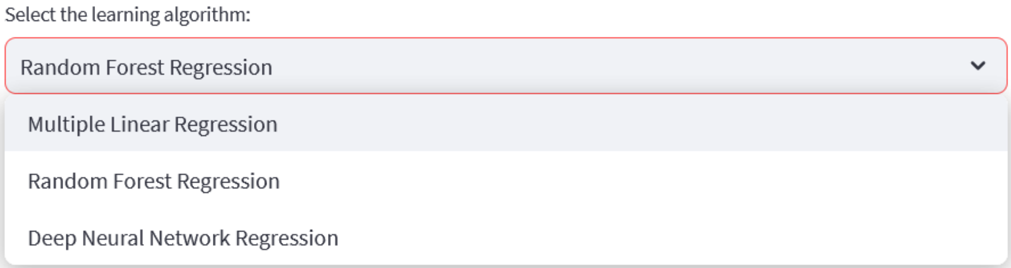
Average Skin Temperature

69.94

Select the learning algorithm:

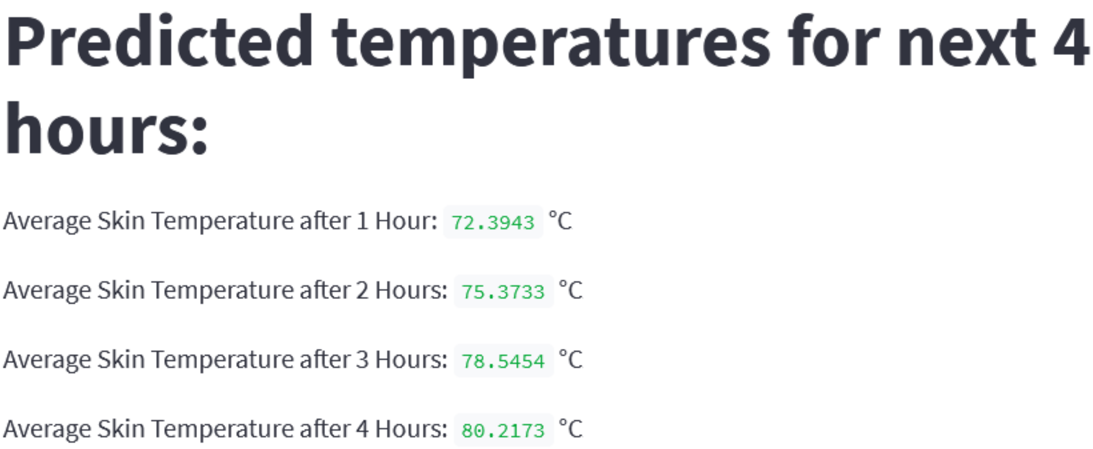
Random Forest Regression

Predict



Select any learning algorithm.

<u>Results on clicking Predict:</u>



CONCLUSION

The Deep Neural Network model & Random Forest Regression algorithm have been used (separately) in this project to predict the output parameters of the blast furnace by taking input parameters. To evaluate the performance of the model, we have used two common metrics: Mean Absolute Error and R2 score to help assess the effectiveness of the model and allow for comparisons with other models.

Overall, the project has successfully demonstrated the usefulness of machine learning & deep learning techniques in predicting skin temperature of blast furnace. The incorporation of class as a feature and the use of the above-mentioned learning algorithms have yielded promising results.

This can be advantageous as optimizing these temperature distributions would lead to substantial savings in the input material of the blast furnace. In the future, further research could explore the use of more features and techniques to decrease the error & improve upon the preciseness of the predictions.

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