Data based approach for magnet design

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Introduction

Magnets play an important role in particle accelerators used for various nuclear physics experiments, most notably at CERN[1]. The magnets ensure that the particles follow the desired path during operation. Therefore it becomes important to have the necessary Magnetic Flux Density profile, i.e. the variation of Magnetic Flux Density along the considered coordinates. Although it is striaght forward to obtain the Magnetic Flux Density profile given the parameters of the magnet, it still remains a challenge to obtain the parameter from the given Magnetic Flux Density profile. Such study can help the engineers get some idea of deisgn parameters such as the length and thickness while designing the magnet. Here we use Machine learning algorithms to detect patterns between the design parameters of the magnet and its respective Magnetic field values, and further try to see the accuracy to which the parameter can be predicted using the data about the magnetic field.

1. Machine Learning

Artificial Intelligence(A.I)[2] is the most developing and expanding technology of the recent times. Machine learning is a part of A.I. which deals with making computers recognize patterns and give predictions without being explicitly programmed. It is a data based computational approach where a certain model is made by referring to a certain existing data, statistically studying it and recognizing the underlying pattern to prepare the model, and then using the model on unknown data, to get the result. The process can be summarised as gathering the data, training the data on some quantity of the data to make the model, applying the model on rest of the data and then checking for accuracy of prediction by various parameter as to what amount does the predictions differ from the actual values. Machine learning is classified in following two ways 1) Supervised learning 2) Unsupervised learning. In case of supervised learning we use labelled data is used i.e. we know the feature data along with the target data which belong to them. In case of the unsupervised learning we use the unlabelled data i.e. there is no knowledge of the target data corresponding to the feature data.

2. Use of Machine Learning for magnet system design.

In our case we take the solenoid magnet. We use the machine learning algorithms to predict the dimensions of the solenoid magnets such as the outer radius, inner radius, length etc. The problem in our case is that of regression, and we use various machine learning algorithms such as KNN and Decision Tree etc. The Magnetic Flux Density variation along the axis for a solenoid magnet for certain design parameter has been shown in Fig 1. We use the value at the centre of the axis Bo and the current density (j/J) as the feature class to predict the length, inner radius and outer radius as the target variable. We begin by unconstraining the parameters one by one i.e. we at first fix two parameters and then use B_o and j to predict the third parameter.

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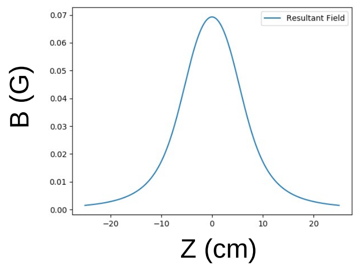

FIG. 1: The resultant Magnetic Flux Density along the axis for a typical solenoid.

Data Source

We have the following equation for the value of B_o(the medium is taken to be air)

$B_o = \mu_o aj\beta$ F(α,β) (1)

the ratios are defined as follows

α = b/a

β = l/a

$F(\alpha,\beta)=\log((\alpha+(\alpha^2+\beta^2)^{1/2})/(1+(1+\beta^2)^{1/2}))$

Here a is the inner radius of the solenoid, b is the outer radius, 2l the length of the solenoid, j the current density and B_o the magnitude of the magnetic field at the centre of the axis of the solenoid. The data were generated using Eq (1) in a self developed Python [3] code. We use the features as B_o and j and the targets are clearly a,b,l. For first phase of analysis we keep two parameters fixed and vary the third one. Example: b and l fixed, we loop through random values of j and a and use them to caclculate B_o. Then from the data generated 80 % is used to train the model and the rest to test the accuracy of the model.

Results

TABLE I: The table shows the r2 score of two algorithms for predicting a keeping b and l fixed.

Algorithms	R2 score
Decision Tree	0.9709
KNN	0.9932

TABLE II: The table shows the r2 score of two algorithms for predicting b keeping a and l fixed.

Algorithms	R2 score
Decision Tree	0.9577
KNN	0.9989

TABLE III: The table shows the r2 score of two algorithms for predicting l keeping a and b fixed.

Algorithms	R2 score
Decision Tree	0.9708
KNN	0.9983

We performedcmachine learning algorithm for our regression problem namely Decision Trees and K Nearest Neighbors. The accuracy of various models have been recorded in Table I, Table II and Table III. We can clearly see that Decision Tree and K Nearest Neighbors are capable of predicting the underlying physics and patterns in the data generated from (1). It is interesting result because both Decision Trees an KNN algorithm are different in their approach. Decsion Tree is about building the tree structure from the training data by splitting it into smaller and smaller subset, whereas in case of KNN algorithm it is about predicting the output based on the closeness of the test variable from the values in the training set. Therefore we see that both the decsion and the distance based model are good for our problem under above conditions.

Conclusion and Future Work

We see that there is a scope of predicting the design parameters for a magnet from certain Magnetic Flux Density profile using learning based algorithms. Further we can investigate the pattern when there is only one parameter fixed and notice the accuracy of prediction, also various other algorithms can be employed to see their accuracy. Further work will be carried and reported.

Conclusion and Future Work

[1] home.cern/tags/magnet

[2] www.wikipedia.org/wiki/Artificial_intelligence

[3] www.python.org