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APPLICATION OF MACHINE LEARNING IN MECHANICAL ENGINEERING

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Abstract- *The industrial world is always evolving and now at this stage, just before the initiation of Industry 4.0, machine learning is changing and going to change mechanical engineering with other different areas related to it, for example, sustainable power source. Machine learning has recently been actualized in mechanical engineering. Data is helping us to improve productivity, malleability, and the nature of the system astoundingly. Machine Learning gives us models to examine these informational collections and actualize them. In this paper, there is a short overview of the methodologies of machine learning in the mechanical engineering field, for example, fault diagnosis, manufacturing process, prediction of crack propagation, condition monitoring of machines, quality prediction and so on utilizing different types of machine learning models, such as, SVM, LSSVM, Deep Learning, and so forth.*
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Keywords: Machine Learning, Mechanical Engineering, Support Vector Machine (SVM), Data Analysis, Fault Diagnosis.

1. INTRODUCTION

Machine Learning is a huge sector with endless possibilities. It is a subdomain of "Artificial Intelligence" which is constantly changing the world. Machine learning is mainly about giving machine ability to learn from people about different scenarios without being notably programmed. It uses different kinds of algorithms to set up links among pieces of information gathered from data. Then it implements it in some trained models. It can be said that machine learning is a process of getting an answer from old data. As we learn from our experience, old data can be called as experience for the machine. In short, the process of gaining knowledge from data is machine learning. [1]

With the continuous progress of science and technology, mechanical engineering is changing gradually day by day. From the traditional and old school mechanical engineering, it is turning into "Electronic Mechanical Engineering". [2] In this phase transformation, artificial intelligence and machine learning are playing vital roles. The hype of the modern days, self-driving car of Google and Tesla, automation in industries, detecting flaws in industrial designs, turning static drawings into the simulation to understand what needs to be changed to give higher efficiency, all of these are the results of applying artificial intelligence and machine learning in mechanical engineering. Today, when machine learning combines with mechanical engineering many doors get opened which were thought to be impossible to unlock just yesterday.

The purpose of this paper is to give ideas about the composition and development of machine learning in this decade in conjunction with the relationship between machine learning and mechanical engineering. Its main scheme is to study how machine learning is applied in the field of mechanical engineering.

2. CONCEPT OF MACHINE LEARNING

Machine learning (ML) mainly focuses on how a computer learns human behavior and interactions and how a machine (computer) reorganizes its knowledge with newly achieved knowledge to improve its performance continuously. As the machine is exposed to new data, it adapts to the situation to give better results. It is an old science or technology that has gained momentum in recent days. It is actually the core of artificial intelligence and without it, computers could not have own intelligence. Nowadays, machine learning is seen in almost every aspect of our life such as financial services, government, energy sector, health care, transportation and so on.

There are various methods of machine learning. Among them, the following three are the most important ones. They are i) Supervised learning, ii) Unsupervised learning and iii) Reinforcement learning. [3]

2.1 Supervised Learning

Supervised learning is the procedure of creating a model that will extract and understand relations among the elements of the old dataset and use those relations and patterns on a new or unknown dataset of the same kind to predict a result. There are two types of supervised learning. They are i) Classification, ii) Regression.

2.1.1 Classification

Classification is the method of separating elements of an old dataset into different classes and comparing the elements from a new dataset to identify which one fits which class, the most.

2.1.2 Regression

Regression is the method of analyzing data from the old data set, extracting relation between them and then applying that to an independent variable of the new dataset to predict the corresponding dependent variable.

2.2 Unsupervised Learning

In unsupervised learning, we have unlabeled data which means input data has no target. We just fit the data in a machine learning model to perform i) Clustering ii) Dimension Reduction [3]

2.3 Reinforcement Learning

In this method, we have an agent and an environment. Now, we want the agent to reach some objective in that environment. Every time the agent wants to reach the objective, it tries with all of its capability and does arbitrary actions. For every action, it gets a good or bad reward and based on the type of reward it understands its way to approach the environment to reach the objective. It is used for gaming, robotics, and navigation. [3]

3. THE CONCEPT OF MECHANICAL ENGINEERING

Mechanical engineering is a broad discipline of engineering that implements the core principles of engineering to the design and manufacturing of different kinds of machines and their parts. [4] It is one of the most diverse and multifaceted fields of engineering. Mechanical engineers work across a huge variety of ways including conceptualizing, designing and manufacturing machines as well as their components. Despite being one of the oldest disciplines of engineering, mechanical engineering continues to grow and evolve with the ever-changing world and adapting itself to its highest usefulness for the people. Mechanical specialists assume significant jobs in practically any industry including car, aviation, construction, biomedical, PCs, hardware, micro-electro-mechanical frameworks, energy transformation, designing thermal devices and nuclear sector.

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4. THE RELATIONSHIP BETWEEN MACHINE LEARNING & MECHANICAL ENGINEERING

In spite of mechanical engineering as a basic field of engineering which is being used in our daily life in almost every aspect with the rapid development of science and technology, it has some shortcomings, such as an unstable system.

In their daily work life, mechanical engineers generally analyze problems to see how a mechanical device might help solve the problem, creating blueprints so that the device can be built, after designing and redesigning mechanical devices, developing a model or prototype of the equipment and testing that, analyze the test result and working according to that and lastly oversee the manufacturing process. [4] In all these working steps of a mechanical engineer in his own field, machine learning can be related to increasing the efficiency of the engineer and giving a better output for mankind. Machine learning algorithms can be used to identify which type of mechanical device can be created to solve the problem, by analyzing the problem. Using machine learning and simulation a mechanical engineer can easily find out the faults in the design which might help to save time and physical and mental labor. It can even eliminate the necessity of prototyping a device and testing that in many cases. In those cases where prototyping is necessary there, machine learning can be used to analyze the prototype test result. During the manufacturing process, machine learning can be helpful by early fault detection, crack propagation detection, data prediction, etc. [5] So, mechanical engineering and machine learning are related in a pervasive way.

Mechanical engineers use different types of tools, engines, and turbines in their daily work life. They are generators, forming press, IC engines, vibration isolators, steam and gas turbines, semiconductor process systems, power-using machines, such as refrigeration and cooling, industrial equipment, including autonomous or semi-autonomous robots used in production, systems for transporting goods inside the industry, and packaging. Almost all these tools are related to machine learning in a way or another. So, it can be said that we cannot tear mechanical engineering and machine learning even an inch apart.

5. APPLICATIONS OF MACHINE LEARNING IN MECHANICAL ENGINEERING

There is an endless application of machine learning in mechanical engineering from different aspects. Machine learning is the key to the automation of an industry which changes almost all the calculations of production and profit of that industry to a larger scale. Nowadays it is changing the industrial sector along with other sectors of mechanical engineering. The following are reviews of some previously published renowned paper on the application of machine learning along with its different methods and approaches in mechanical engineering.

5.1 Mechanical Fault Diagnosis using One-Class Support Vector Machine

Firstly a lot of data on mechanical failure is gained which features that are dubious in many ways. So, the memory model, which will be used in this application for fault diagnosis has to adjust to the evolving data. A dynamic memory model using One-Class Support Vector Machine (OCSVM) is created in this methodology. The data gathered from the failure is then fed into the newly created OCSVM memory model to extract and reserve the result of the diagnosis. This memory model then processes every failure type to extract features to build the ideal dissemination area in high dimensional feature space. Minimum decision function is a great advantage of this methodology and model. This function is used to perceive the failure state, which shows the contrast between data related to failure and the ideal dissemination area in the high dimensional feature space. [6]

Mechanical fault diagnosis is standing on the thought of measuring the similarity and dissimilarity in the feature of a currently running procedure with a type of failure, which is previously known to us and reaching a conclusion depending on the matching degree. [7] So, it is mandatory to have memory and organized previous failure information for running diagnosis. This is why a dynamic memory model based on OCSVM is used in this aspect. In any case, the running condition of mechanical equipment is changing persistently and comparable failure shows enhanced features in various formative stages. For fault diagnosis to be successful, a lot of data is required and at the same time the data have to be or in an organized manner. The previous or existing memory model must be updated with the new failure characteristics. Here comes proposed OCSVM. OCSVM contains the previously introduced dynamic memory model, This OCSVM is used to build up the ideal and higher dimensional distribution space of every failure type. OCSVM has an Incremental learning algorithm different and quiet unique than other known machine learning models. The unique feature of this algorithm is, it dynamically adjusts the higher dimensional distributional space and the least decision function. Then this algorithm judges the type of failure as it has compared.

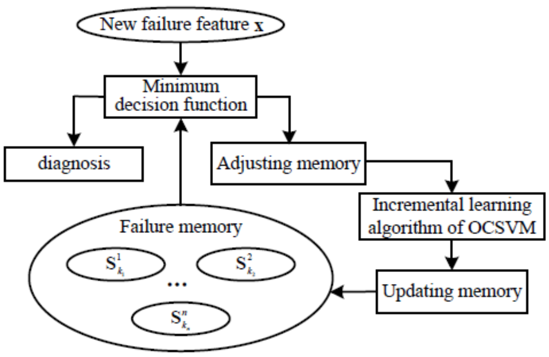

Figure 1: Internal incremental algorithm for fault diagnosis. [8]

From the algorithm or model, we can clearly understand the process of training the model and identifying the failure types at the same time. The latest type of failure can be added at once and the previous existing failure data can be updated using incremental learning. [8]

5.2 Machinery Condition Prediction Based on Wavelet and Support Vector Machine (SVM)

If we give labeled data to SVM, the algorithm outputs an optimal hyperplane which categorizes new examples. It is a supervised learning method of machine learning as we have discussed earlier. It has shown advantages in solving problems with limited sample and high dimensional pattern recognition. The soft failure of mechanical equipment makes its performance drop, from time to time and it occupies a large proportion. We can evaluate this performance by early state monitoring and analyzing data. [9]

Mechanical equipment is used for long term operation. When a fault appears in the machinery, it may cause a lot of troubles to the whole production system. It can even start a chain reaction which can result in stopping the whole operation to be operated normally as well as causing damage. These effects can be both for short terms and long terms. These performance degradations are called, the soft failure of mechanical equipment. Temperature, noise vibrations, etc. are some parameters and signals of running machinery. These vary from time to time. It is possible to identify the working condition and predict the future trend of mechanical equipment using this kind of signal. Presently mechanical equipment's state prediction methods are of three kinds. One of them is the prediction method which uses existing knowledge to predict which problems and fault can appear and be seen in the running machinery. The second one is the prediction technique using models that predicts the upcoming problems and faults in machinery using models mainly based on mathematics. The last one of the prediction methods is a prediction method that uses previous usage data to predict the faults in machinery which can appear in the near future. [10]

Vibration is a prime signal that takes place in any mechanical machinery and when the machine fails, the wavelength or other features of this vibration change. We can learn a lot of things from this vibration signal and its changes, as it contains a lot of important information. Wavelet analysis is a method to deteriorate the consolidated information of various frequencies into signals on various bands. Wavelet analysis mainly consists of wavelet transform which is used to project various sequences of vibration into various scales, and these scales are called "Band". This helped us to get estimation about different frequencies using wavelet analysis. Different characteristics of vibration sequence worked as the base of the SVM model which is established to obtain estimated results using the reconstruction of sequence. Fig. 2 demonstrates a flow chart of estimating the intensity of true vibration using SVM and wavelet analysis.

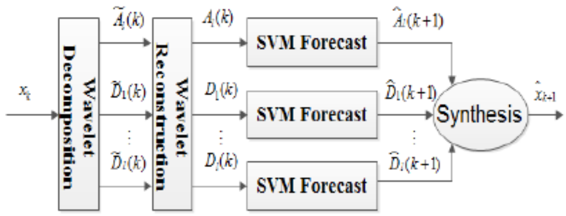

Figure 2: Flow chart of estimating vibration intensity through wavelet SVM. [10]

Here authors showed how wavelet and SVM theory can be combined to produce a more efficient regression model and estimate the future or upcoming condition of machinery. [10]

5.3 Prediction of Material Mechanical Properties with Support Vector Machine (SVM)

This application of machine learning features the application of SVM, setting up a non-linear mapping. This non-linear mapping is mainly done from collecting factors that influence different material performances related to several mechanical properties. [11] The simulation result of the author of [12] showed that the founded model has different capabilities. It can preferably generalize learning and efficiently predict mechanical properties. So, this model is worthy to be applied and spread in the research of material performance.

Material mechanical properties refer to those, that involve a reaction under the action of forces and surroundings. Common samples with common techniques in material testing machines must be used to determine these properties. From these properties, we can get a perfect stress-strain curve. Using this curve we can calculate the accuracy of the model that is created for this application. This model is established on mechanical properties with material composition and methods, to a limited degree, at that point we can diminish test times, increment proficiency and understand the streamlining of the procedure. Moreover, we can harness progressively valuable data from the current test information and encapsulate its standards, which is very critical for the improvement and advancement of the material hypothesis.

Many authors and researchers have applied Artificial Neural Network for non-linear mapping. An ANN which has been prepared efficiently using essential training data sets can efficiently utilize the relationships which can easily predict mechanical properties. Moreover, if we get new data, then it is even possible to upgrade the network by training it again with the latest data. [13]

But, it is hard to overcome the problem of overfitting and generalization. These problems occur in the lengthy process of training the model and difficulties to reach the neighboring ideal point in the network. These drawbacks of ANN made it essential for another machine learning approach to take its place. Support Vector Machine (SVM), is the supervised learning model that has algorithms that analyze data for regression and classification. SVM is mainly based on statistical theories. SVM is very much efficient and can learn a lot of information which is way more than the other existing machine learning models. This is why it has been widely used in the research field of machine learning internationally. SVM is based on the main theory of Structural Risk Minimization that eliminates the problems of overfitting and allows the model to be trained properly. If we compare SVM to ANN we will see that SMV has a better principle in the theory side and it needs fewer parameters setting. SVM algorithms can be widely used for estimating material mechanical properties.

In this prediction model of mechanical properties, we have some steps. At first, factors are selected on the basis of which, this model will run and give the result. Then the most important SVM model is constructed and analyzed. After that the process parameters are optimized and at the end of the process, we get the desired output. [12]

5.4 Machine Learning-Based Approach of Image Processing in Mechanical Engineering

Machine learning (ML) is now the hot topic of technological and other related fields. The use of this approach is increasing day by day in almost every sector. Back to some years, machine learning was only confined in theory and pages of books and was only applied to some specific field. But the decrease in the price of computing power and technology, and the increased availability of these has opened the door of machine learning in various sectors. Application of machine learning in mechanical and plant engineering is at the primary stage but it can be of great use in this field as we have discussed earlier. In the coming days, machine learning will be the driving force of innovation in mechanical engineering. ML and Artificial Intelligence (AI) are confused with each other often. AI is the effort of duplicating the human mind or conscious and ML can be said as the primary step of it. But there are a lot of differences between them, their goals are different at a large scale. The most important difference is that ML is already here around us but AI is still a matter of conjecture. [14]

ML can provide us with a human-like vision which can be used in identifying crack types, material quality, etc. Traditional image processing reaches its limit as it tries to judge a surface. But human eyes have the power to easily identify and justify texture, quality, objects, and patterns present in an object, different types of structures, etc. Human eyes can easily identify defects in any object with the least training. Different types of human-like vision sensors and equipment are used to process images. In ML we can easily train the model with ideal structure but the traditional image processing requires a lot of defect catalogs. Many ML-based image processing systems are especially being developed to be used in the industrial sector for image processing and analysis. These models are even working beyond human capability by processing images and detecting faults in a very efficient way which is impossible for any human eye.

Now, unknown and new characteristics of products can be learned using the human-like vision image processing based on ML. There is now no need for a huge amount of defect libraries. So, as a result, the production time is decreasing and the rate of production is increasing.

Though ML has a lot of possibilities in this field, there are some drawbacks which have to be discussed. The first drawback is the unavailability of data for training the model. Then this process requires some expert feedback to check the result to ensure that the model is working fine which is not always available. In this approach, the image resolution and size of the files are some problems that occur in transmitting or storing data. Moreover, there is a slight chance of the ML system to be tampered by someone.

At this current stage, ML has a long path to go and the path is filled with both prospects and provocation. But it can be surely said that those who do not follow the path of ML and deny to attach them with data-driven technology will be far behind in the next stage, Industry 4.0. [14]

5.5 Machine Learning Techniques for Supporting Renewable Energy Generation

The field of production of energy from renewable sources is spreading day by day. The recent developments of the mechanical sector make it essential to extract energy from various renewable sources. These sources are sun and other ample natural sources such as wind, geothermal, etc. The energy sources which we have been used for a long time such as natural gas, coal, petroleum, and other energy sources are causing many problems to nature and these have now become a weapon for the politics. [15]

Currently, all renewable power plants totally depend on the natural parameters for harnessing energy. So, as a result, we cannot completely control them and prepare a plan for our plant for the upcoming production.

In a power grid, it is important to anticipate the measure of the amount that will be produced later on, including the plants which use sustainable energy sources as their fuel as fluctuation in the energy extraction rate affects the physical structure of the whole grid, just as the personal satisfaction of clients who receives power from those grids. Since the sector of sustainable power source plant is expanding day by day, the size of the power plant and the design of the power plant are some important factors that must be considered carefully. A power grid is a complex structure, so the management of a power grid is not an easy task that can be done by one man or two. So, smart power grids that use renewable power sources must be managed carefully and precisely. In [15] there is an overview of various machine learning procedures that are used to control a renewable energy plant or smart grid.

Sustainable power source assets related to sun and wind are changing from time to time and the subsequent shift in the energy harnessing limit can cause vital problems in the power grid. Renewable energy power plants depend on the ecological factors at a large scale. The energy extraction of this type of plants depends on the speed of the wind, overcast sky, the intensity of the solar radiation, etc. Power plants also depends on the yearly or daily cycles of the earth and the climate, such as solar energy can only be produced during the day. So, it is very much important for sustainable energy source based power plants to extract energy from the source when it is available and reserve it for later use while utilizing a part of the power at the same time of production. Wind, photovoltaic energy, etc. are costly to reserve. So, a careful administration of energy extraction is needed. At the point when the natural resources cannot produce sufficient energy to cover the need, traditional sources like gas power plants are used to compensate for the deficiency.

The previously mentioned difficulties have inspired the utilization of machine learning (ML) to help better the administration of energy production and utilization. Diverse ML methods are utilized in various phases of a sustainable power grid, contingent upon the necessities and the qualities of the issue.

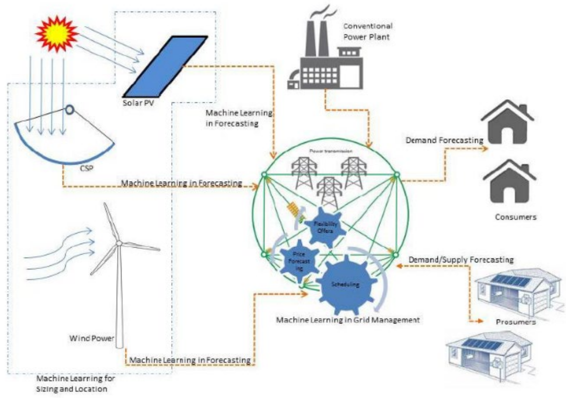

Figure 3: Outline of a power grid with incorporated sustainable sources and its utilization of ML methods in various strides. [15]

Machine learning approaches are used in forecasting renewable energy generation. The auto-regressive moving average (ARMA) and auto-regressive integrated moving average (ARIMA) models are used for wind speed forecasting.

Several types of Multiple regression method including least-square SVM were used with other models for performance estimation of PV (Photo Voltaic). Trial results demonstrated that the SVM model outflanked the other ML models with an exactness rate of more than 27%. The solar irradiance can be forecasted using ARMA or SVM. [16]

Different machine learning approaches have been used to determine plant location, size, and configuration. Machine learning models such as MIRABLE, MTBF, CART, FFT, and many others are used for managing renewable energy integrated smart grid. These models are used for balancing supply and demand, grid operation and grid data management. [16]

It is exceptionally hard, to sum up, the ML-based models for each part of sustainable energy extraction and the related system, yet solid strategy is essential including the distinctive estimation and other related models to more readily upgrade the grids overall efficiency and effectiveness. ML methods have been effectively utilized in the arranging of sustainable energy source plants, dependent on accessible information with sensible precision.

5.6 Machine Learning in Cyber-Physical Systems

A cyber-physical (likewise styled cyberphysical) system (CPS) is a component that is controlled or checked by computer-based algorithms, firmly coordinated with the Internet and its clients.

Cyber-physical system = Machines + Sensors + Computing. Robotics and intelligent machines (Self-driving cars, drones, material handling…) are examples of cyber-physical systems. Autonomous vehicles are prime examples of the fusion of mechanical engineering and machine learning. Ultra-smart embedded systems are also applications of machine learning.

6. CONCLUSION

This paper reviews the creation and improvement as well as the relationship between machine learning and mechanical building. It additionally outlines the important uses of machine learning in the mechanical engineering field.

Hypothetical and practical research demonstrates that intelligent technology has been broadly utilized in all parts of the mechanical system, combined with the disclosure of knowledge and dispersed artificial intelligence, machine learning and other computer technology, which makes machine learning progressively compelling in the mechanical system and different zones. Due to the undeniably increasing challenge in the machinery industry, the hybrid intelligent design, monitoring, control, diagnosis system based on fuzzy logic, neural network, expert system, will be a new research hotspot so as to improve the degree of its smart intelligent control. These applications have extremely encouraging prospects.

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8. NOMENCLATURE

Symbol	Meaning
CART	Classification and regression trees
FFT	Fast fourier transformation
MTBF	Mean time between failures
OCSVM	One class support vector machine
SVM	Support Vector Machine