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MACHINE LEARNING AND ITS INDUSTRIAL APPLICATIONS: AN OVERVIEW

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Abstract: Machine Learning is the most popular concept in use now because of its nature of ability to learn by itself through experience and also able to work even in presence of large amount of data. Use of machine learning has extended into various domains including computer science, mechanical engineering and electrical engineering domains. Machine learning algorithms are applicable in various industries as automobile, agricultural supply chain, manufacturing and machine design. The present paper reviews the latest trend of applications of the machine learning in industries and the challenges to be overcome for its more widespread applications. In particular the paper describes the different techniques for machine learning in manufacturing industries, supply chain management and automobile industry. Recent developments in machine design domain are also discussed.

Keywords: Machine Learning (ML), Support Vector Machine, Machine Design, Manufacturing, Supply chain, Automobile, Artificial Neural Network.

1. Introduction

Many knowledge-based systems are designed to automate processes such as expert systems for decision support, intelligent-scheduling systems for concurrent production, and fuzzy controllers. In order to implement these knowledge-based systems there is a requirement of the expert knowledge.

ML is study of computational models on computers for progressively improving the performance on a specific task in order to make accurate forecasts [1]. Machine learning (ML) enables computer programs to automatically improve their performance by handling the high volume data efficiently. It comes into use when exact information can't be interpreted and extracted for abundant datasets.

Machine learning is used to extract relevant data. Various techniques are used to learn the data. These techniques are classified as shown in the figure 1.

Supervised Learning – It uses labelled input and output data in order to create training algorithms. The input dataset is divided into train and test dataset for prediction or classification. It comprises of algorithms such as Decision tree, Support Vector Machine, Classification algorithms.

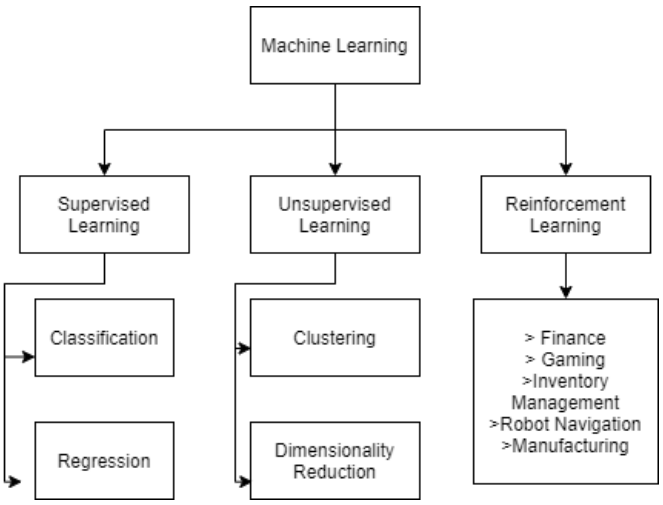

Figure 1 Classification of Machine Learning Techniques

Unsupervised Learning – There are no labelled input and output data. The algorithms try to find intrinsic patterns within the data. Whenever new data occurs, it uses the previously learned features for determining the class of the data it belongs to. It comprises of PCA and clustering algorithms.

Reinforcement Learning – Also known as the hybrid model, here algorithms take actions to maximize cumulative rewards.

1.1 Fields of Mechanical Engineering

A lot of research has been done in various sectors of mechanical engineering, which forms the basis of most businesses and is crucial for the development of mankind. Most of these researches aim at improving the elements of the sectors which can be achieved with the help of evolving technologies. Advancement in technology demanded substantial changes from the fields like manufacturing, industrial designing, thermodynamics, supply chain management etc. Owing to the changes these fields upgraded their frameworks, enhanced their techniques, adopted new technologies, all while keeping in view one of the major tenets of the businesses; improving quality, increasing speed, and reducing manpower. Deployment of machine learning in these fields has served several purposes. Various algorithms of machine learning have taken over the traditional methods used in industries. From the simple task of classifying objects in the industry to detecting faults and failure more adeptly than humans and automation of difficult tasks, machine learning performs all the tasks with highly increased efficiency. Results, of using machine learning models, trained on a huge amount of data, to search for patterns in new data, have shown promising results which further adds to the reasons for the wide adoption of machine learning. Further in this paper, the numerous applications of machine learning techniques in the fields of mechanical engineering have been discussed.

1.2 Advantages of Machine Learning approaches:

- They can handle big data.
- Analytical efficiency can be improved because these techniques are more sensitive to outliers in the sample and capture the interactions among variables.
- Discrete variables are handled by machine learning techniques in contrast to conventional regression models.

2. MANUFACTURING INDUSTRY

The manufacturing industry is of immense importance while considering the economy of any country. Responsible not only for the modernization of the primary sector but the industrial sector also serves as the intermediary between primary and tertiary sector. The industrial revolution transformed most of the agrarian societies into economies based on large-scale industries, mechanized manufacturing, and factory systems. The first three industrial revolutions spanned over 200 years. Innovation in technology and changes in business environments brought forth the Industry 4.0, named as the fourth industrial revolution. It focuses on entirely digital manufacturing enterprise. The development of numerous technologies and methods can ascertain this possibility. Numerous technologies like the Internet of Things, Big Data Analytics, Cloud Computing, etc., can be used in various industrial processes, improving the efficiency of the process, reducing manpower, and improving the quality of work. Machine learning is one such appropriate and promising tool through which a huge data of information can be utilized to perform myriads of manufacturing tasks.

2.1 Challenges

The development in various sectors of the world urges the manufacturing industries to change accordingly. Changes do not take place in the manufacturing processes only but also adopted by to-be-manufactured products, business processes of the company, and collaborative networks. Revamping of the manufacturing sector in accordance with the technological trends has been initiated by numerous countries throughout the world. Listed below are some major challenges the industry is facing:

- Flexibility and Agility in Supply Chains
- New manufacturing management paradigms
- Sustainable Manufacturing Process and Products
- Adoption of advanced manufacturing technologies
- Innovation in products, services, and processes

In order to meet all the challenges, the manufacturing domain has to become more dynamic and complex. With customized products in trend, there is a requirement for flexibility at the product level in a cost-effective manner. One of the major requirements in the manufacturing industry is the maintenance of machines. If the time for maintenance, the machine that requires an instant address, and the type of maintenance required can be predicted before major failures, huge losses to the industries can be prevented. Also, domains that are to be optimized like monitoring and control would require the availability of huge amounts of data. Such kind of data poses lot of challenges and also may demand new methodologies for storing, processing, and management.

Some of these challenges of complex manufacturing industries can be well met with machine learning techniques. This data-driven approach helps to finds complex patterns, linear or non-linear, from the raw data provided and creates models that can be implemented on a new set of information for detection, prediction, classification, regression, or forecasting.

2.2 Applications

Machine Learning has seeped its way into manufacturing showing promising results and highly increased efficiency. Several algorithms of machine learning are being used for different tasks in the industry. Automation of machines increases the speed of processes and reduces the cost of development with a decrease in time needed by supervisors. The expert knowledge required for automation is being conveniently acquired with the help of Machine Learning. Problems incorporating classification of objects by domain experts with classification models machine learning provides [2].

2.2.1 Fault detection: Fault detection can be detected by Bayesian network which is a directed acyclic graph where the nodes represent random variables and their conditional dependencies are derived by directed arcs linking the nodes [3]. ML models are capable of identifying the occurrence of geometric defects (impeding application of additive manufacturing like aerospace), quantifying the deviation, and providing guidance of geometric error compensation. The application of ML algorithms such as K nearest neighbor and naive Bayesian have utilization in building predicting models such as predicting the failure of airplane components before they stop working [1]. Vibration data is collected by piezoelectric accelerometers as time-domain signals for the healthy bearing [4].

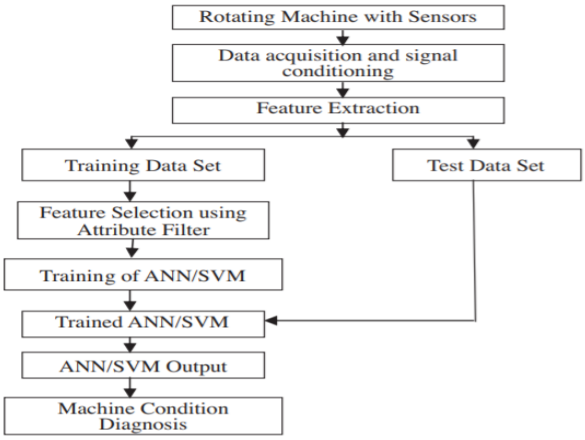

Figure 2 Flow chart of bearing health diagnosis

2.2.2 Automation and Quality Improvement: Machine learning algorithms have been applied in various processes like cutting, turning, milling, drilling, boring, grinding. ML increases sustainability as it leads to the permanent availability of uniform, objective cutting process knowledge which enables manufacturers to benefit from their machining equipment resulting in the reduce of time, money, energy, and natural resources [5]. Supervised learning is employed for investigating the decision-making and process planning problems in manufacturing. Cost estimation can be accurately achieved by machine learning models.

2.2.3 Lean manufacturing: ML techniques have applications in LEAN manufacturing systems as well by using just-in-time (JIT) and Kanban tools. The results of the implementation of ML into LEAN manufacturing systems show that the neural networks and decision trees are two most practical algorithms with abilities in adjusting the number of Kanban's in a dynamic JIT manufacturing environment. Classification and regression trees (CARTs) and Artificial Neural Networks are used to determine numbers of Kanban in a dynamic environment which makes it increasingly practical to operationalize the Kanban setting problems.

3. Supply Chain Management

3.1 Bullwhip Effect - This is a well-known issue in the area of supply chain management. Also known as Forrester effect, it can be considered as a demand distortion in the supply chain. It can be visualized like a wave when a whip is lashed and the wave propagates from one end of the whip to another while increasing in amplitude. Similarly, a slight distortion of demand on the side of the retailer travels upstream via the wholesaler and other tiers of the chain straight up to the manufacturer. This can be better visualized using the following figure 3.

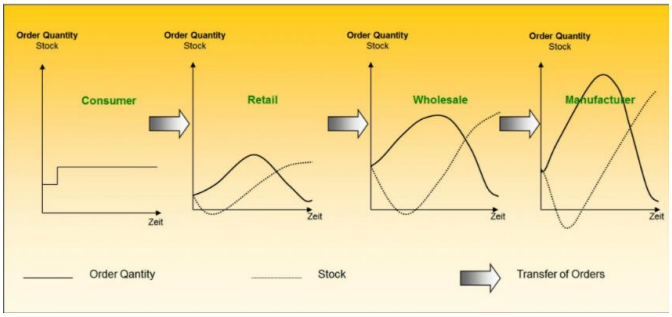

Figure 3 Bullwhip Effect

Major causes of Bullwhip Effect:

- Order batching – This occurs when smaller orders are rounded and clubbed together so as to meet manufacturing constraints.

- Price fluctuations – Irregularities and cost changes can impact the judgement and purchase capabilities of the customer which in turn impacts the manufacturing based on irregular demand and distortion in information.
- Demand information – Too much reliability on past demand information in order to predict trends and discover information can lead to bias where the current demands and trends may go unnoticed for longer periods of time and eventually cause an imbalance between the actual and the predicted requirements.

3.1.1 Impact of Bullwhip Effect

- Incorrect inventory levels – Too much or too little inventory causes disruptions in the supply chain and negatively impacts its performance.
- Additional costs – If the inventory levels are too high, then additional holding costs have to be borne by the company. Moreover, if additional investments have been made in enhancing infrastructure to meet the inflated demands, then these costs are almost irreplaceable and have profound financial implications.
- Deterioration in relations – Insufficient inventory can lead to shortages and increased lead times. This can cause delays in fulfilment of orders at the customer level which can prove detrimental to the relationship between the company, its suppliers and the end customers leading to decrease in overall trust and brand loyalty.

3.1.2 Applications of Machine Learning in Bullwhip Effect:

Information sharing has become crucial in order for all components of supply chain to work together effectively. This integration has to occur across all stakeholders. With the advent of E-commerce and online business companies are tending towards more “agile” supply chains [6]. This can help companies become more flexible and adaptive to changes but in turn makes them less reliant on others reduces the need to have long term relationships. Therefore, it is of extreme importance to make accurate forecasts about the demand.

The forecasting techniques used in analysis include:

- Naïve Forecast
- Multiple Linear Regression (MLR)
- Neural Networks (NN)
- Recurrent Neural Networks (RNN)
- Support Vector Machines (SVM)

Among all the above mentioned, RNN and SVM are the most accurate forecasting techniques. Wherein average, naïve and trend forecasting are the worst. But according to statistical analysis, there is no significant difference in terms of the accuracy of forecasts among all techniques [7]. The ever-increasing amount of data makes it easy to apply various tools and strategies in order to draw insights. However, when the volume of this data increases, it becomes difficult to store and process it. The use of Artificial Neural Networks (ANN) can prove to be a game changer in this scenario. Presently, there are three broad fields where ANNs are employed in supply chain analysis. They include:

- Optimization
- Forecasting
- Decision support

In recent years because of higher accountability requirements and an industry wide effort toward digitalization, data availability in the oil and gas industry has increased significantly.

3.2 Agricultural Supply Chain (ASC)

To ensure security and safety of food in future, use of big data analytics and machine learning play a key role. Studies identify that ML algorithms in providing real-time analytic insights for pro-active data-driven decision-making in the ASCs and provides the researchers, practitioners, and policymakers with guidelines on the successful management of ASCs [8].

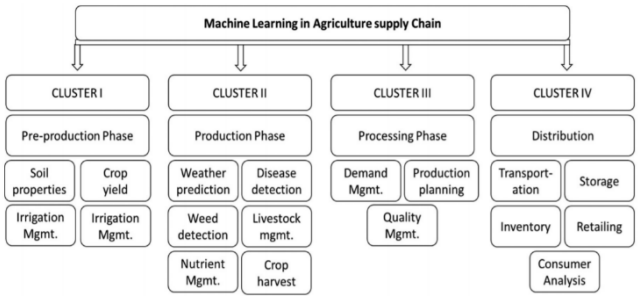

Figure 4 SLR (Systematic Literature Review) Presentation Framework [8]

3.2.1 Challenges for ASC:

Agricultural supply chain is very different from other industries. The goods are perishable therefore it needs to operate on a similar basis such as the FMCG (fast-moving consumer goods) industry. However, there are many external factors such as location, weather, climate, pests etc. which cannot be fully controlled or even predicted. Therefore, machine learning algorithms will play a crucial role in the upcoming days to make better forecasts and predictions and in this process make the supply chain more efficient and productive.

The growing awareness of economic, social, environmental aspects of ASCs, led to increase in pressure from many organizations in developing sustainable food production and consumption. Most of the practitioners and researchers agree to the fact that current ASCs need a drastic shift towards sustainability to comply with the United Nation's 2030 agenda of Sustainable Development Goals (SDGs) [10].

The figure 5 briefly describes the various components of Agricultural Supply Chain. It also attempts to explain which domain of Machine Learning is suited individually for each domain. ML has various applications such as increase in supply chain visibility and product traceability which require in exploring the possibilities of integrating ML data with other technologies like block chain etc. [11].

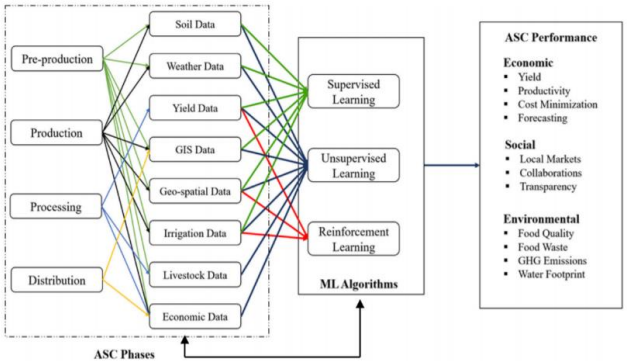

Figure 5 A ML-ASC Performance Framework [9]

4. Automobile Industry

Due to increase in customer demands and revenue, the automobile industry plays an important role in the development of the global economy. Technological innovations aim at meeting the customer requirements as safety, seat belts, air bags which help in avoiding too much of injuries. Anti-Brake Systems help in increasing stopping distance even on slippery pavement. There is huge potential for machine learning in realizing the dream of automobile industrial revolution.

4.1 Applications

4.1.1 Fuel Consumption Prediction

Ability to model and predict the fuel consumption is the ongoing challenge in preventing fraudulent activities in fleet management. Fuel consumption of a vehicle depends on various factors such as distance, load, vehicle characteristics, driver behavior, road conditions, traffic and weather. The best option for this is the random forest algorithm which uses bagging and feature randomness when building each individual tree. Such a model is useful in detecting the fuel fraud which depends on parameters such as distance, location, elevation and speed where the actual consumption of the vehicle can be compared against the predicted value [12].

4.1.2 Environmental Challenges

The sustainable development of mankind is a matter of concern to the whole world. Machine learning can predict and control the emission rates of exhaust gases of an automobile. ANN (Artificial Neural Network) is the most widely used algorithm in controlling and monitoring pollution. Since machine learning based solutions are highly adaptable, it can be easily optimized with other algorithms making it more robust. Laboratory testing and Field testing are two ways to analyze automobile emission such as carbon monoxide, Nitrogen oxide and CO2 etc., which are expensive. With the introduction of ML technologies, they become more efficient even in presence of large amount of data.

4.1.3 Power management

Automotive industry is facing following challenges:

- Producing vehicles with increased electrical/electronic components
- Growth in fuel economy
- Reducing emissions without affecting vehicle performance, safety, and reliability.
- Machine learning can be used efficiently in power management in automobiles.

4.1.4 Pedestrian Crash Frequency

Pedestrian crash frequency is one of the major cause of fatalities. Various traffic accidents can be detected with the help of ML patterns by developing a prediction model that automatically classifies the type of injury severity. Machine learning can play a huge role in preventing such accidents.

4.1.5 Fault diagnosis

Fault diagnosis of automobile hydraulic brake system can be achieved with ML. The brake system is a critical safety component necessary for the safe operation of the vehicle [13]. Support Vector Machine(SVM) shows better classification ability in identification of a various faults in the gearbox and it can be used for automated fault diagnosis [14]. Using machine learning in fault diagnosis for various other components such as steering wheel, brakes etc. can be done in an efficent way.

5. Machine design

5.1 Introduction

Artificial intelligence especially machine learning and deep learning has changed the perception of the

potential approach towards tackling the problems in mechanical engineering. Advanced Artificial intelligence combined with the other technologies like Internet things (IOT), 3D or 4D printing, Advance Robotics and Virtual reality is evolving machine design to a new era of generative design where the designer can itself think for the good design without any environmental constraints so that one can reach the best form of the design what till now may not have reached. Research on artificial intelligence will lead the design ultimately to self-adaptive, self-healing, self-repairing and self-improving. All we can say that the machine will interact with environment just like the human being would.

5.2 Challenges in Designing

- Complex structure can lead to higher design spaces.
- Environmental constraints decorate to achieve efficient design.
- Due to complexity Innovation in Machine design is fewer.
- Increase in accuracy and speed.
- Increase in efficiency, quality and flexibility.

Whenever we start the process of making a component or machine the first step of it would be a Mechanical design. When the complexity of the material structure rise it gets difficult for the material to optimize its mechanical behavior so it is not possible for conventional method to reduce the problem. Similar problem arise for small system designer as they want to make even smaller components, hence to make machine compact, easier to carry and store. In account to this problem Machine learning models have high datasets that relate to its functions, properties, and behavior in different regime this material can be used that can help to explore the design space faster.

5.3 Applications

5.3.1 Optimize and automation: We should appreciate our modern technologies and advancement in the field of machine intelligence as in many businesses now a day's machine can work automatically without any human interference and they can find the best optimize solution for the difficulties faced during the processing by their self-learning skill. This reduces the chance of error that might occur if tackled by even experts. It certainly increases efficiency and flexibility.

5.3.2 Detect analyze and predict trend: Smart robots and generative design can recognize, detect and predict various trend and pattern. Due to these ability innovations in field of machine design is rapidly increasing.

5.3.3 Research: Knowledge based system with Artificial intelligence came into use firstly in 1980s. The revolution of AI in designing has made a great impact. Already the change of designing process from handmade design to CAD modeling was disruptive therefore this revolution will be more disruptive (i.e. groundbreaking). Due to this technique the design formed will be critically complex but thanks to advanced research that they are no more difficult than conventional designs. Already these generative designed components are used in aircraft and other systems. But this all is low level artificial intelligence. In high level artificial super intelligence, the machine would be able to adapt itself according to surrounding where it can operate with complete autonomy. Self-driving car is the post child of artificial intelligence. Application like robotic clinician is the future of A.I. where the robot will be able to diagnose the illness better than human doctors. Recent research falls on four categories they are suturing, Improving surgical material, Evaluating surgical skills and surgical workflow.

5.4 Effects of ML applications in Design

A.I and M.L has already affected product design industry in substantial manner. It has affected broadly in two ways.

- Firstly, artificial intelligence will help to reduce the laborious task that product design engineer need to perform like finding appropriate design, fixing errors, overcoming failures, reducing design space and optimal solutions. These tasks can be done quickly and efficiently with help of machine learning.
- Secondly, advance A.I. will act as assistance to the designer to process and diagnose complicated design. This machine intelligence will work at the designer's elbow helping to develop innovative and generative designs.

Project Dream-catcher: This is an environment made by Autodesk researcher by using artificial intelligence and machine learning. Unlike old version we just need to select the design goals, environmental constraints, material type and manufacturing capabilities. With all this data the intelligence will explores all permutation of thousand or even millions of data over design choices to give us the optimized solutions using algorithms like neural networks. It even uses cloud computing technique. As it will process millions of 3D models, it will learn itself the best possible material, the parts and how they are related with what they can do. Hence it will provide the best compatible machine design with regard to given data. It is still a developing project as till now it can only be used in some area like aircraft parts and even bike frames. Autodesk even hope that after some days all the design or automobile industries will use generative design once it gets commercialized.

The efficiency of the ML models depends on the amount of pre-processed dataset we gather. This dataset is properly pre-processed on the existing knowledge of material's physical and chemical properties even with all considerable environmental constraints. In some cases machine learning help to perform some task which generally human can't perform due to tons of data or limited time. With machine intelligence (i.e. machine learning with artificial intelligence) the designer need to train the algorithm over all the environmental constraint rather than focusing on effective designing. Due to generative designing the design will be self-adaptive towards the changes as well as it will learn with more experience and data it encounter just like human being henceforth increasing its efficiency.

6. Conclusions

The growing data is a challenge in all types of industries that needs research on tools that discover unique properties of the data. Machine-learning algorithms are useful in a variety of real-world industry applications. Many companies in the world provide commercial implementations of these algorithms [15].

This paper describes all machine learning techniques in manufacturing, automobile, supply chain management and machine design. It explains the fault diagnosis in automobile and manufacturing industry and the most accurate machine learning algorithms used for them. It discussed challenges faced by machine design and supply chain management and also how they are solved by using machine learning algorithms.

The paper concludes that the A.I and M.L has greatly affected manufacturing, agriculture, automobile and product design industry in substantial manner. Machine learning find application in fault detection, Automation and Lean manufacturing, agriculture supply chain and in automobile industry for fuel consumption predication and power management.

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