<u>Physics-1 Project</u>

MACHINE LEARNING IN OPTICS

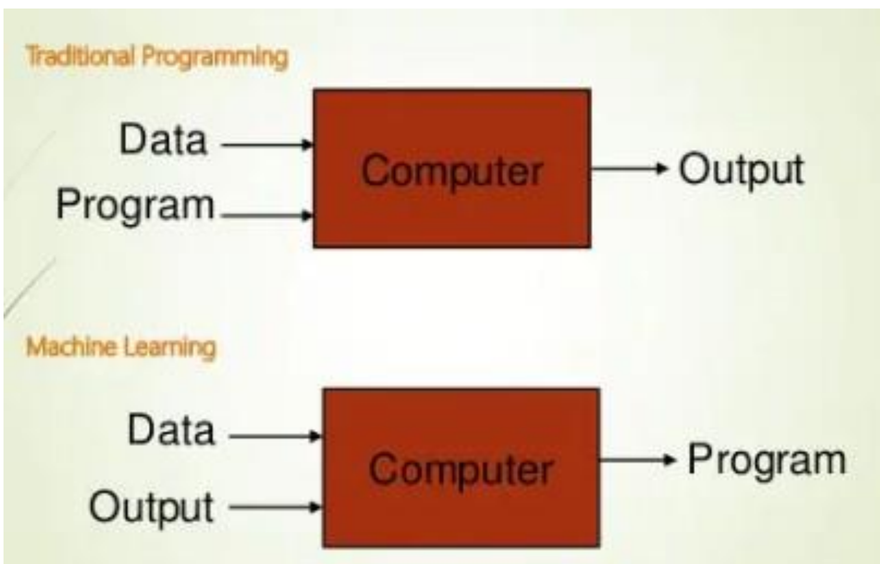
Abstract

Recent years have seen the rapid growth and development of the field of optics, where machine-learning algorithms are being matched to optical systems to add new functionalities and to enhance performance. Our aim here is to highlight a number of specific areas where the promise of machine learning in optics has already been realized. We also consider challenges and future areas of research.

INTRODUCTION

What is Machine Learning?

It is the use and development of computer systems that are able to learn and adapt without following explicit instructions, by using algorithms and statistical models to analyze and draw inferences from patterns in data. It improves their performance at a task with experience.
It is about teaching a computer to automatically learn concepts through data observation by training it with a huge dataset.



Machine learning (ML) techniques have been developed and applied to optical communication in both the physical layer and network layer for years. Various algorithms from ML communities powered a wide range of aspects in optical communication, involving digital signal processing (DSP), optical performance monitoring (OPM), signal detection and analysis, proactive fault management, network automation, and optical sensing, etc. Driven by this growth in the volume of data and improvements to computing power, ML has successfully evolved into deep learning (DL), which addresses complex and large-scale problems with robust, adaptable, and efficient solutions.

Optical networks

Optical networks constitute the basic physical infrastructure of all large-provider networks worldwide due to their high capacity, low cost and many other such properties.
They are now penetrating new important telecom markets as datacom and there is no sign that a substitute technology might appear in the foreseeable future.
Different approaches to improve the performance of optical networks have been investigated, such as routing, wavelength assignment, traffic grooming and survivability.

Why use Machine Learning with an Optical Application problem if we can use equations to predict or optimize a particular optical device?

Machine Learning shines when there are a lot of input parameters to be optimized. First, if in our optical problem there are for example more than 10 input device dimensions to be optimized then we can easily employ machine learning. Comparing and optimizing 10 or more parameters one by one yourself is a tough job. Secondly, what if the data which we collected experimentally has some unknown noise factor which is never taken care of in equations. In this case, machine learning can be used to predict new values which will take into account the unknown noise of the experimental kit. So I think these 2 factors/cases make the application of machine learning in an optical problem very useful.

However, a major problem that also arises is the unavailability of datasets required online. There are no open-source datasets available for any optical application. This is majorly due to the absence of any big online optical community. Often, one has to make his own datasets of many data points, which requires time and effort.

OBSERVATION

Machine learning has affected almost every industry and area of scientific research, including engineering. Although limited literature on Machine Learning in optics engineering is found, Machine learning adoption has been valuable and garners a lot of interest in this field and the rate of research in this area is growing rapidly.

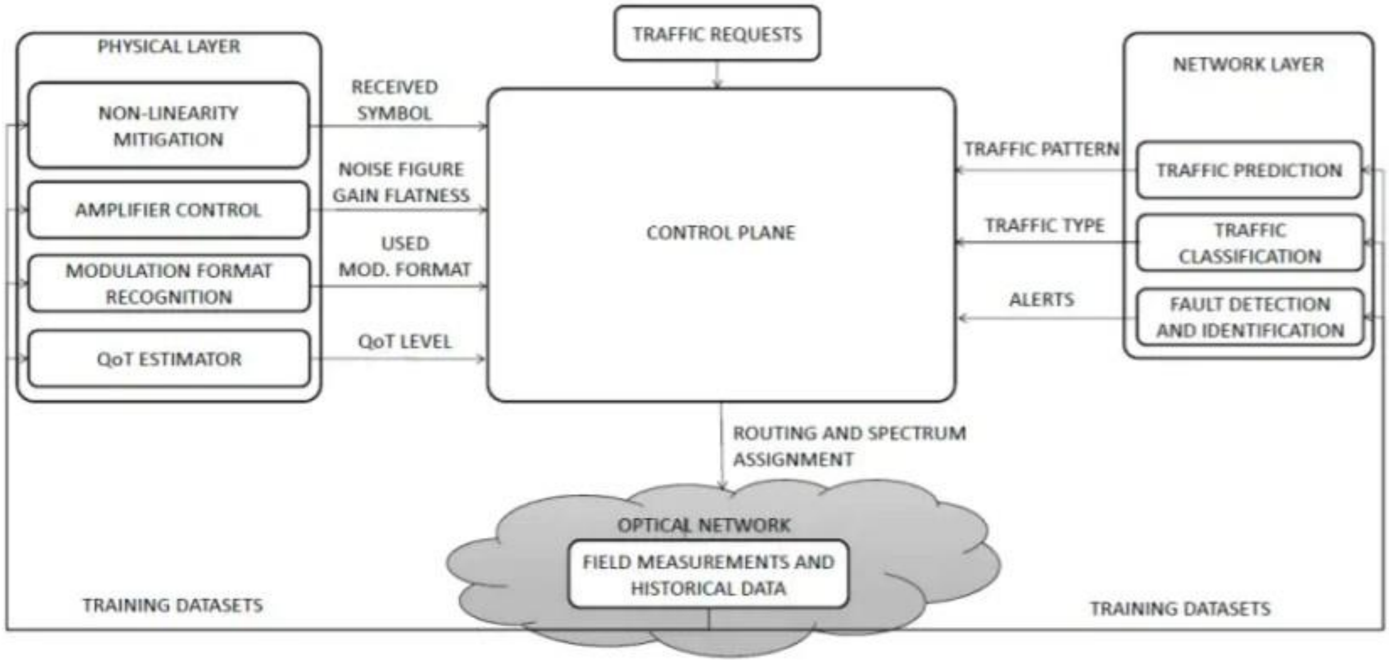
Here are some of the fields in optics where machine learning is used:-

- Quality of transmission estimation
- Optical Amplifier Control
- Non linearities litigation
- Application of machine learning in optics

APPLICATION OF MACHINE LEARNING IN OPTICS

Traffic prediction models for Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) have attracted an increasing amount of attention in recent years. Thanks to the fast development of vehicular computing hardware, vehicular sensors and citywide infrastructures, many impressive applications have been proposed under the topic of ITS, such as Vehicular Cloud (VC), intelligent traffic controls, etc. These applications can bring us a safer, more efficient, and also more enjoyable transportation environment. However, an accurate and efficient traffic flow prediction system is needed to achieve these applications, which creates an opportunity for applications under ITS to deal with the possible road situation in advance. To achieve better traffic flow prediction performance, many prediction methods have been proposed, such as mathematical modeling methods, parametric methods, and non-parametric methods. Among the non-parametric methods, the one of the most famous methods today is the Machine Learning-based (ML) method. It needs less prior knowledge about the relationship among different traffic patterns, less restriction on prediction tasks, and can better fit non-linear features in traffic data. There are several sub-classes under the ML method, such as regression model, kernel-based model, etc. For all these models, it is of vital importance that we choose an appropriate type of ML model before building up a prediction system. To do this, we should have a clear view of different ML methods; we investigate not only the accuracy of different models, but the applicable scenario and sometimes the specific type of problem the model was designed for. Therefore, in this paper, we are trying to build up a clear and thorough review of different ML models, and analyze the advantages and disadvantages of these ML models. In order to do this, different ML models will be categorized based on the ML theory they use. In each category, we will first give a short introduction of the ML theory they use, and we will focus on the specific changes made to the model when applied to different prediction problems. Meanwhile, we will also compare among different categories, which will help us to have a macro overview of what types of ML methods are good at what types of prediction tasks according to their unique model features. Furthermore, we review the useful add-ons used in traffic prediction, and last but not least, we discuss the open challenges in the traffic prediction field.



Quality of transmission estimation

The concept of Quality of Transmission generally refers to a number of physical layer parameters, such as received Optical Signal-to Noise Ratio (OSNR), BER, Q-factor, etc.

Which have an impact on the "readability" of the optical signal at the receiver.

Such parameters give a quantitative measure to check if a predetermined level of QoT would be guaranteed.

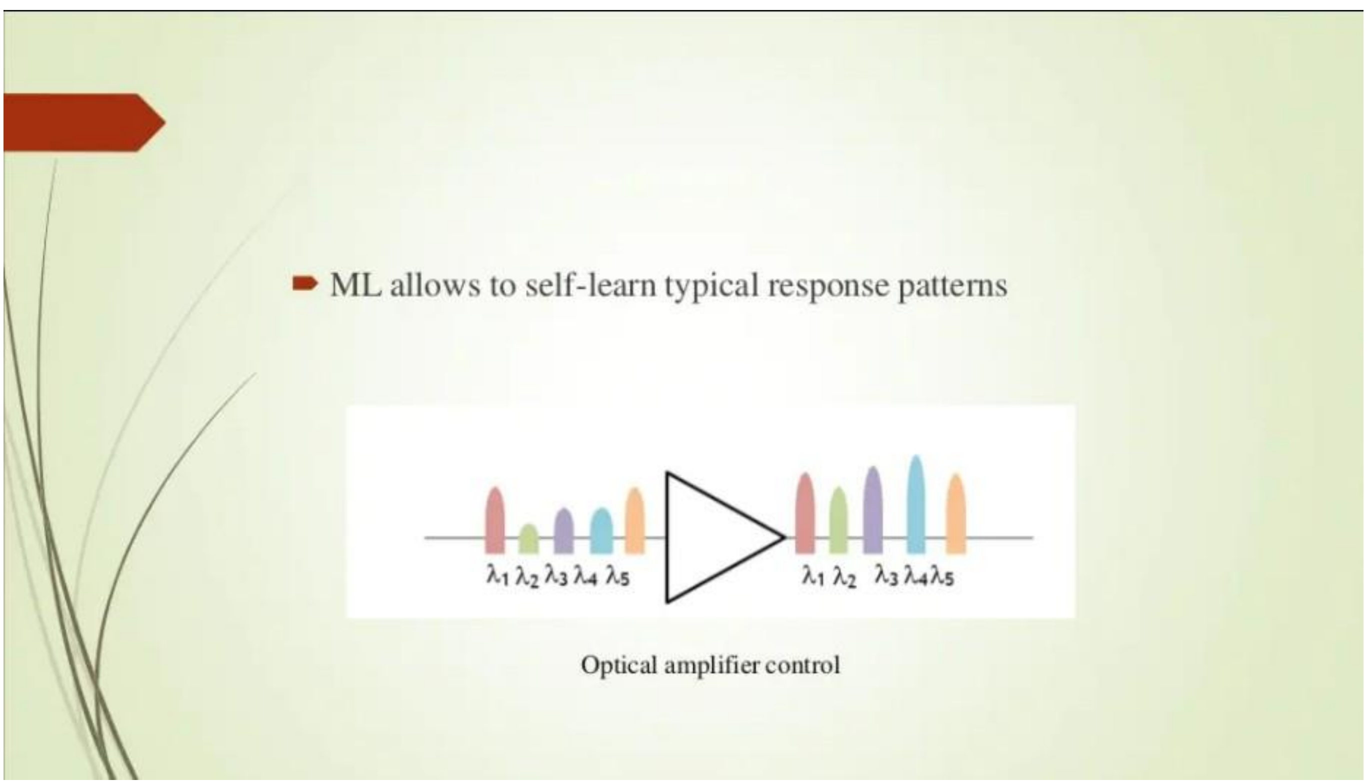
Conversely, ML constitutes a promising means to automatically predict whether unestablished lightpaths will meet the required system Qo'T threshold.

Optical Amplifier Control

When adding/dropping channels into/from a WDM system, EDFA gain should be adjusted to re-balance output powers.

➡ An automatic control of preamplification signal power levels is required, especially in case a cascade of multiple EDFAS to avoid that excessive post-amplification power discrepancy.

➡ML regression algorithms can be trained to accurately predict post amplifier power excursion in response to the add/drop of specific wavelengths to/from the system.

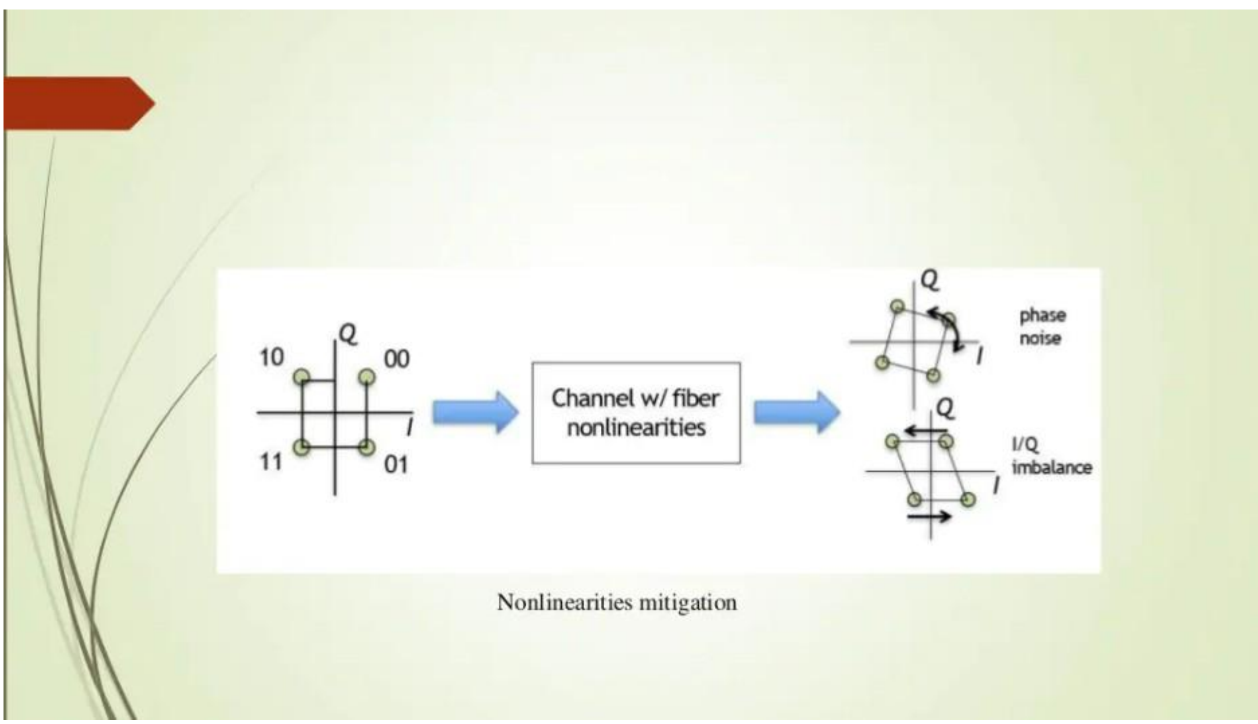


Non linearities litigation

Optical signals are affected by fiber nonlinearities Kerr effect, self phase modulation (SPM), cross-phase modulation (XPM). Q factor, Chromatic Dispersion (CD), Polarization Mode Dispersion (PMD).

Traditional methods require complex mathematical models.

ML models can be designed to directly capture the effects of such nonlinearities, typically by creating input-output relations between the monitored parameters and the desired outputs.



Conclusion

In Order to conclude this, we will say that with machine learning being so prominent in our lives today, it’s hard to imagine a future without it.
Like:-

Manufacturing
Manufacturers are only in the early stages of adopting machine learning. In 2020, only 9% of survey respondents were leveraging artificial intelligence in their business processes.
Machine learning tools can be used for various manufacturing purposes, including monitoring equipment performance and condition, predicting product quality and forecasting energy consumption. With the ongoing advancements in the field of machine learning, we can expect more robots in manufacturing premises in the near future.
Among many other benefits, using machine learning in manufacturing can reduce costs, enhance quality control and improve supply chain management.

Automotive and Self-Driving Vehicles
Tesla, Waymo and Honda are among the car development companies exploring the possibility of deploying self-driving cars. And while manufacturers have already presented cars with partial automation, fully autonomous vehicles are still under development. Machine learning is one of the main technologies that can help to turn these dreams into reality.
Deep learning, a class of machine learning algorithms, can help improve perception and navigation in autonomous vehicle manufacturing, including path planning, scene classification and obstacle and pedestrian detection.
As new technologies continue to unfold, machine learning algorithms can be used more productively. The future of machine learning will open multiple opportunities for businesses.

Intelligent Photonics Technology Development

"Intelligent" means that photonics technology with the upgrade functionality, which is enabled by machine learning techniques, is outperforming conventional photonics, which could be laborious, be time/cost consuming, and deliver limited performance.

Investigation of the light-matter interaction highly depends on optical microscopy, which allows the localized observation of an object in a controllable three-dimensional space and simultaneously translates the interaction into images or spectra. For further quantification of the image or spectra with correlated structural information, conventional studies rely on additional characterizations such as atomic force microscopy (AFM), transmission electron microscopy (TEM), and Raman spectroscopy. In the following two examples, we highlight the fact that ML shows great potential to develop new interpretation tools, resulting in user-friendly all-in-one technology.

Decoding technology beyond the diffraction limit

With the fast-growing development of nanotechnology, sophisticated structures and their miniaturizations have become mature tools. The resulting challenge is to accurately resolve faint optical signals from a limited number of atoms or molecules, which are very likely to be buried in noise. Moreover, the larger the extent of the nanostructure control is, the larger the database of the relevant optical parameters. In this case, ML can play the role of an unprecedented interpretation method, replacing conventional algorithms or manual operations. Recent works have employed ML to predict the bandgap 2,3,4, Fermi level 5, and optical spectra of nanophotonic particles and metasurfaces 6,7,8,9,10. Moreover, Aharon and coworkers proved that deep learning can efficiently mitigate the adversarial effects of noise 11.

The same situation occurs in optical data storage. Nanomaterials are leading a large movement towards optical storage methods with ultrahigh capacity, ultralong lifetime and ultralow energy consumption. However, their subtle features are difficult to read out accurately. High-density optical data storage is limited by light diffraction. To overcome this problem, Wiecha et al. developed a robust ML-based read-out technology enabling encoding multiple-bit information. Optical information of silica nanostructures is stored in scattering spectra or simply as RGB values from dark-field imaging. A neural network was trained to output 4-bit encoding values upon the input of both X-polarized and Y-polarized RGB datasets and the scattering intensities. The demonstrated information retrieval of the network was almost error-free, so that the network was further expanded to 9-bit encoding sequences, leading to a 40% higher storage capacity than that of blu-ray discs. This new encoding technology has enabled up to nine bits of information per diffraction-limited area, far beyond the one bit of information per area of traditional technology. The ability of neural networks to find hidden underlying patterns and form non-linear decision boundaries within datasets makes them ideal for solving such problems.