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An Overview on Application of Machine Learning to Emerging Frontiers in Civil Engineering Science

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Abstarct

Civil engineering has evolved from mere "constructing buildings" to "intelligent tailored structures" with the gradual introduction of advanced design and manufacturing tools such as additive manufacturing, computer aided design (CAD), structural health monitoring and more recently, internet-of-things (IoT). However, challenges in terms of optimizing the process parameters, selection of appropriate materials, standardization of the process, quality control coupled with predictive maintenance of ageing structures has in recent years doubled like never before. Hence, a multi-disciplinary approach involving a healthy synergism of data science, data analytics and civil engineering has made possible the applications of techniques machine learning (ML) to address several of the prevailing challenges. In recent years, several publications have successfully emerged surfaced in this direction and show much promise towards an exciting future specific to "intelligent tailored structures". In this overview we briefly look at the prevailing scenario in terms of "valued": application of machine learning to various sectors in the domain specific to civil engineering.

Keywords: Structural health monitoring; Machine learning; Data analytics; Predictive maintenance

Introduction

Human beings rely on structures for their protection. In the days of the past, or the by-gone era, caves and rock formation were a source of protection. As time gradually advanced an understanding of the behaviour of materials and structures revealed noticeable improvement. The technology to assess, enhance and monitor the strength, integrity and life of a structure took a gigantic leap to a state as of this day wherein the application of machine learning (ML) are being safely considered for the purpose of automating a whole lot of intensive tasks specific to the human being involved. This has resulted in a better and more efficient usage of energy and resources while considerably increasing both safety and overall quality of life.

Current Research on Machine Learning Applications to Civil Engineering

Machine and deep learning include the various standard algorithms that can be effectively used for the prediction of various aspects of Civil Engineering at multiple levels. Application of Machine Learning (ML) in Civil Engineering is currently focused on aspects and intricacies specific to structural health monitoring (SHM), process optimization, disaster forecasting, mining and exploration, to name just a few important ones. The huge data from previous records can be put to effective use for the training of these models that can, in most cases, make fairly accurate predictions. For certain special cases both the model-based learning and physics-based algorithms are currently being used to achieve certain representation, which is often difficult using the standard algorithms.

Structural health monitoring

Machine Learning (ML) applications for Civil Engineering is useful and rather limited. Further, most of the available data in this connection is primarily concerned with Structural Health Monitoring (SHM) of structures. The idea of structural health monitoring (SHM) as a predictive maintenance up until failure,

wherein the health of a structure is continuously monitored using an array or collection of sensors (to include both direct and non-destructive). These sensors help in detecting flaws and other damages intrinsic to the structure, which can eventually be diagnosed using various methods. This approach enables in increasing the working life and safety of the desired structure while concurrently contributing to limiting costs incurred towards both maintenance and repair. The SHM of civil structures can be categorized as shown in the flowchart in Figure 1 [1]. The image based structural health monitories (SHM) employs an algorithm that aids in predicting the occurrence of vibrations in civil structures using computer vision technologies [2]. The vibration-based SHM is primarily continuous monitoring of the signal during dynamic events. Up until recently, multiple machine learning (ML) algorithms have been used in each of these steps. However, this is no longer an issue with the application of deep neural networks [1]. Machine learning (ML) does find for itself restricted usage in applications specific to civil engineering due to lack of extensive quality data. To overcome this hurdle S. V. Reddy and co-workers have put forth and discussed the possible implementation and advantages of the physics-based models [3].

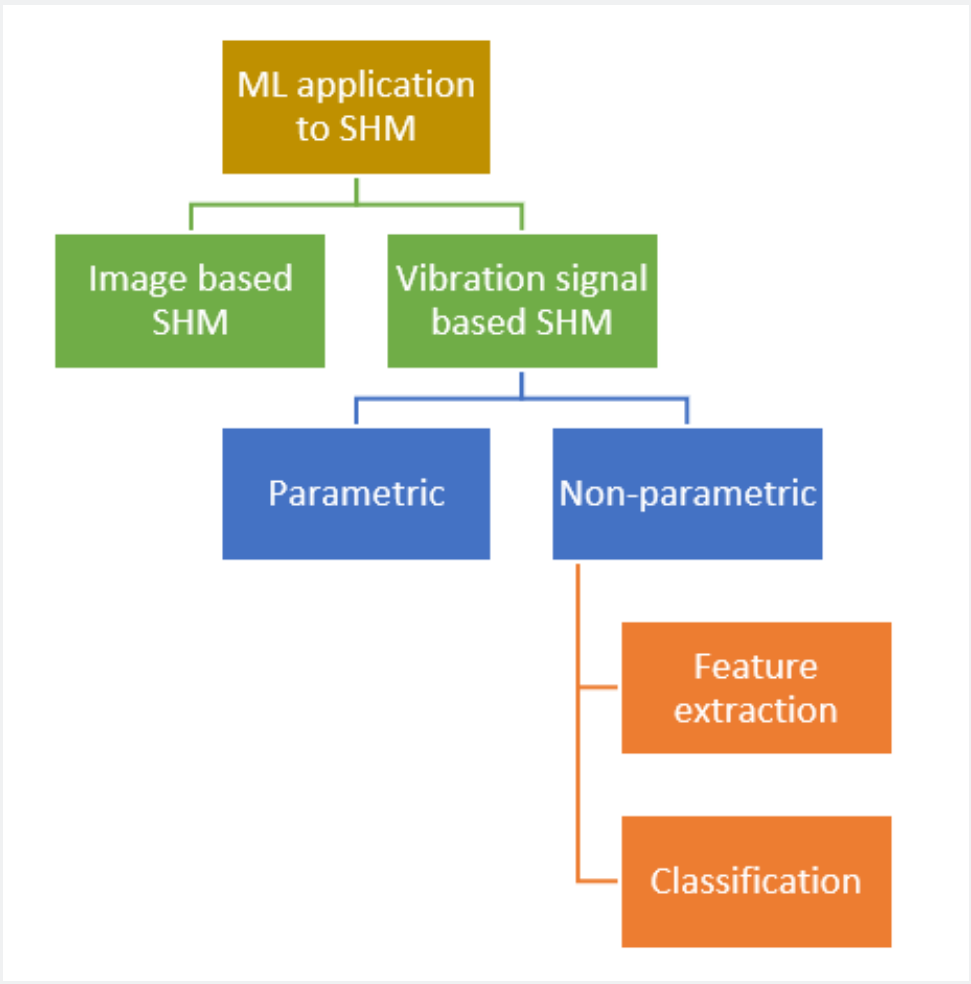

Figure 1: Structural health monitoring in civil engineering applications [1].

Machine learning (ML) integrated inspection for the purpose of structural health monitoring (SHM) of pipelines have the capability to pin-point both the presence and location of defects, which up until now an inspection gauge had to be manually moved over the entire length of the pipeline to both spot the defect and identify the same [4]. Machine learning (ML) algorithms can be used at every stage of structural health monitoring (SHM), namely:

a) damage detection

b) damage assessment

c) damage prediction [1-7]

This technology is being widely used in the mechanical industry for the purpose of structural health monitoring (SHM) of machinery [6,7].

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Mining and Exploration

Documentation of machine learning (ML) application for mining has been in use for quite some time. This has essentially been for the purpose of mineral exploration, exploitation and reclamation. Clustering algorithms, support vector machines and deep learning methods are chosen and used for the purpose [8]. A growing depletion of the resources has encouraged geologists to opt in favor of using machine learning (ML) techniques for processing satellite and airborne data (remote sensing data) for the purpose of ensuring efficient mineral exploration. This has contributed in a positive manner to enabling in

a) the mapping of various minerals, often referred to as mineral prospectively mapping

b) mineral processing [9,10]. Mineral prospectively/ resource mapping involves an integration of the various geological, geochemical, geophysical, and remote sensing data to assess the likelihood of mineralization in a given area.

Additive Manufacturing

Additive manufacturing (AM), or 3-D printing, has brought a revolution due to its unique "user friendly approach". Three-D printing of structures for homes and offices are becoming increasingly commonly these days [11]. This process uses various machine learning (ML) techniques during both construction and parameter optimization for the prime purpose of improving quality. This technology has noticeably transformed the process of construction. The process of construction that used to take months and in a few cases years, can now be achieved in a few days. Customized shapes and sizes with an increased focus on achieving high strength at vulnerable areas and/or locations of a structure can now be easily achieved using the technique of machine learning (ML) [12,13]. It safely allows for the physical components to be made from virtual three-dimensional (3D) computer models by building the component layer-by-layer until the entire structure is built or completed.

Disaster Forecasting

Prediction of natural disasters can be vital because thousands of human lives and animal lives can be saved, which otherwise would be in jeopardy. Also, property damage and infrastructure damage can be easily prevented or at least the desired precautions can be taken to minimize both the extent and severity of damage. A lot of effort can be seen this regard and machine learning (ML) application can be seen in six-disaster management areas which include the following

a) early warning damage

b) damage assessment

c) monitoring and detection

d) forecasting and predicting

e) post-disaster coordination and response

f) long-term risk assessment and reduction [14].

These disasters often include earth quakes, floods, forest-fires, tornadoes and hurricanes, and even volcanoes. A real-time flood prediction developed using a neuro-fuzzy model for the urban areas does accurately forecast the occurrence floods in an area in advance [15]. Such technologies contribute to improving both the lively hood and quality of living in disaster prone areas.

Conclusion

This overview article summarizes machine learning (ML) technologies that are currently in demand and their integration with various core problems in civil engineering and allied fields. The material presented and discussed highlights the capability and potential of machine learning (ML) to solving these problems. It is certain that an implementation of machine learning (ML) can improve the prevailing technologies by several order while concurrently reducing the risk and burden of several professions, thereby enabling in the creation of a safe working environment. The machine learning (ML) techniques also ensure an efficient use of energy, resources and capital towards improving quality of life and thus ensuring safety. Overall, it is safe to conclude that the prevailing era of machine learning (ML) integrated technologies is beginning to emerge as a promising simple, easy, safe, efficient and well-connected approach for the use of all concerned and involved.

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