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Analysis on the application status and prospect of intellectualization and digitization in civil engineering

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Abstract. Nowadays civil engineering is facing the transformation of the combination of intelligent, digital and other modern new technologies. Civil engineering, as a traditional industry, may not be able to meet the efficiency and requirements of today's technological society. In order to adapt to the development of society, civil engineering is trying to transform to other disciplines. In recent decades, intellectualization and digitization have begun to affect the way civil engineering works and operates. In fact, intellectualization and digitalization can affect every stage of the whole civil engineering process, including the design stage, construction stage and service stage. The purpose of this paper is to discuss the application of intelligence and digitization in civil engineering. Some of the most important applications are listed and further explained, and the future development prospect is preliminarily analyzed and prospected. By enumerating the innovation brought by intelligence and digitalization to civil engineering, it inspires people to carry on more in-depth thinking, further adaptation and new adjustment to the future civil engineering.

Keywords: intelligence, digitization, artificial intelligence, machine learning, deep learning.

1. Introduction

With the development of science and technology, the age of information and innovation has arrived. In the past decade, intelligence and digitalization have become more and more popular and gradually permeated every other field [1]. Although civil engineering as a traditional industry, but also gradually began to combine with intelligence and digital. The impact intelligence and digitization have on civil engineering is undoubted and massive. New technology and invention like artificial intelligence and Internet can be utilized in many different aspects in civil engineering [2]. With intelligence and digitalization, an opportunity for the transformation and upgrading of design, construction, supervision and other aspects in civil engineering appear and is getting more and more popular [3].

Currently the applications of intelligence and digitization have combined with civil engineering in many aspects, such as Building Information Method (BIM) and Intelligent Information System [4]. More and more specific utilization appeared, while at the same time, some obstacle may hinder the development. However, People working in the field of civil engineering may find it hard to accept the new skill required for intelligence and digitization. Some may even oppose the procedure of intelligence and digitization because when information gets transparent, no extra benefit can be attained. All these opportunities and challenge must be analysed closely, and solution need to be proposed so that intelligence and digitization can better serve human beings.

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Intelligence and digitization can help in design stage, construction stage and usage stage. In the design stage, intelligence and digitization can act as the aid of structure design, analysis and force calculation [5]. In the construction stage, intelligence and digitization can reduce the risk worker may face during construction [2]. In the usage stage, intelligence and digitization can provide efficient way for operators to monitor the condition of structure and do structural performance testing [6]. This paper summarizes the influence of intellectualization and digitalization on civil engineering and looks forward to the future of civil engineering under the influence of intellectualization and digitalization.

2. Application of intelligence and digitization in design stage

The intelligence and digitization used in civil engineering design is an essential trend as the design procedure in the past is complex and inefficient. Nowadays the procedure of design is supposed to be quick and accurate, which requires designers to find better way to create both economic and precise design scheme. The ways that intelligence and digitization involve in design stage is explained as follows.

2.1. Computer aided drawing (CAD)

The structure that was designed used to be sketched by hand. This method has several disadvantages. Firstly, different Drafter may draw the same element or component differently, causing some inconvenience for readers to identify and for engineers to communicate efficiently. Secondly, drawings that drew by hand will take longer time and if some error is made, designers cannot find out easily. Thirdly, the drawings that are completed need to be preserve carefully, so that drawings will not be damaged. The auxiliary drawing software like Auto CAD, Pro/E, UG and 3Dmax, however, enable designers to draw on computers. Nowadays CAD is one of the most used CAD software.

The international CAD industry has gone through four different stages. (1) From 1960s to 1970s is the pioneering period. (2) Form the late 1970s to the mid-1980s is the first period of development. (3) From the late 1980s to early 1990s is the second period of development. (4) From the mid-1990s to the present is the third development period.

In 1960, Ivan Sutherland developed SKETCHPAD using the TX-2 computer manufactured by MIT Lincoln Laboratory, which is considered the first step in the CAD industry. The main goal of CAD technology was two-dimensional drawing, which continued until the late 1970s and later developed relatively independently and steadily as a branch of CAD technology [5]. However, due to significant industry application demand in the late 1970s to mid-1980s, surface modeling and physical modeling techniques developed rapidly. Numerous CAD/CAM software applications have evolved, and the global CAD market has entered its first development stage. After that, a fresh wave of change in the CAD industry pattern occurred in the late 1980s and early 1990s as a result of the rise in popularity of single user computer systems, the development of parameterization technology, and the advancement of feature modelling technology. Finally, Computer software and hardware have undergone constant innovation and improvement since the mid-1990s. In particular, the quick emergence of microcomputer 3D CAD systems, which has ushered in the third growth phase of the global CAD industry, has been significantly impacted by the increase in processing power [5]. CAD has improved to meet people's need through these four stages and nowadays CAD even do not rely on drawing on computer, drawing can form automatically if designers import the model into the computer. The disadvantages mentioned are eliminated or reduced to a large extent by using CAD.

2.2. Computer aided analysis

The deformation and forces are regularly calculated to check if the structure designed is eligible. The calculation was calculated by hand or calculator, which is both time-consuming and complicated as some of the formula in civil engineering is complex, thus difficult to calculate. Computers, however, can be computed and calculate complex formula more easily. Meanwhile, with the model designers are also creating a three-dimension figure that cannot be achieved in paper, thus the structure becomes more vivid and precise to witness. For instance, in Midas civil, designers can create a simplified model to

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represent the bridge in the software, and add various kinds of load to the model, then the computer can calculate the internal force and deformation of the structure, checking that if the concrete and steel is enough to hold the demanding force. By using this tool, designers of the bridge do not need to do all those complex calculations, thus saving time to a large extent. The development of modelling represents that information variability and transparency is a key feature in construction nowadays. Big and well-known designing institutes require their staff to have modelling and analysis skill, which enable them to accommodate working task and requirement. This shows the importance and popularity of computer aided analysis.

2.3. Design evaluation and optimization

When a design plan is completed, designers should come up with the idea to identify if the plan is well-suited in safety and economic aspect. This might be a sophisticate procedure due to the reason that a civil engineering structure cover a lot of sides, making it difficult to consider every side and add all sorts of fee together. Among the various AI techniques that have been created, fuzzy logic, expert systems, evolutionary algorithms, and artificial neural networks have long been the most widely used traditional methods in the review of design and the processes of optimization [1]. Expert systems are a subset of artificial intelligence (AI) in general. They emulate the method used by experts to solve problems and employ a symbolic way to represent knowledge [7]. The concept of fuzzy logic was created by the extendibility of classical/binary logic. It is used to solve difficult real-world problems where classical/binary logic fails and to model ambiguous phrases (short, long, extremely lengthy, etc.) mathematically in a way that is akin to how people think [8]. The machine learning method that imitates the work neurons do in the human brain is called an artificial neural network. It is designed to function similarly to how signals and stimuli are processed by neurons in the human brain, how a result signal is transmitted when the stimulus climbs and reaches above a threshold that is being set. The stimulus and signal from human's brain are the artificial neural network's input data, the network's weight serves as the threshold, and the output data appears as the response to the stimulus [9]. An evolutionary algorithm (EA) is a general metaheuristic optimization method that is based on population. It is also a subset of evolutionary computation [10]. With these technologies that linked with machine learning, the plan of the design can be a majorization.

3. Application of intelligence and digitization in construction stage

The most time-consuming and complex process during civil engineering is construction stage. It involves preliminary survey, construction on construction site and its supervision work. Some of the work contain danger and complexity for people, but nowadays intelligence and digitization can fit in some of these jobs or task, the problem can be sorted out more quickly. The innovation below depicts the utilization of intelligence and digitization in civil engineering.

3.1. 3D printing

3D printing is a very popular topic in recent years, many news or research report that a variety of complicate structure can be printing using a computer. As to civil engineering domain, 3 printing have various kinds of utilization, too. It combines with civil engineering to form a new term called construction 3D printing. Building information model (BIM)-based construction 3D printing uses the principle of layered materials. 3D printing divides the model into layers, each layer has a specific thickness in one direction, then 3D printing will generates the corresponding algorithm. Finally, the numerical control system completes the automatic construction along a predetermined path [11]. 3D printing leads to the innovation of new materials that are suitable for 3D printing. First, a sizable database is created to store all the information currently available about materials, including their components, preparation techniques, and performance traits; Second, in order to choose the materials with the best performance given the requirements, machine learning techniques are applied; After pattern detection and extraction, the database's contents are compared and studied to determine which materials are the

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best [11]. Not only can the materials being printed by 3D printing technology, for the experiment in lab, the structure tested during experiment can also be created using 3D printing.

3.2. Building information method

BIM was proposed by Professor Eastman of Georgia Institute of Technology in 1975. It aims at modelling the structure, and then all sorts of calculation can be done by computers in several minutes. The engineering practice of Shanghai centre has proved that by applying BIM technology, engineers can cut rework by 60%, save construction time by 10%, and enhance project efficiency by eliminating 90% of drawing errors [11]. A construction defect management system was created in 2014 by Kwon et al. [12] employing augmented reality, picture matching, and BIM technologies. The image matching function of the system eliminates the requirement of quality inspection in the field, reduces the cost of rework in the field, and can automatically detect the size error in the field. According to a 2015 analysis by Bai et al. [4], By using BIM technology, prefabricated building development can move toward intelligence and information and the production of prefabricated parts can be greatly improved.

3.3. Digital twin (DT)

A digital twin is defined as a data connection between the actual world and its digital representation and is a realistic digital depiction of assets, processes, and systems [13]. People can use digital twin to operate digital modelling and dynamic data transmission. More research is required to speed up the digital transformation of the architectural, engineering, and construction (AEC) business, even though the concept of "Digital Twins" (DTs) has the potential to radically revolutionize asset design, production, and maintenance. [14]. The technology of digital twin today is not perfect, and right now more is done by researchers to improve it.

4. Application of intelligence and digitization in service stage

In the service stage, the main assignment is to make sure that the structure still works well, and the safety of the structure must be examined regularly and precisely. Intelligence and digitization provide a more convenient and efficient method for completing these affairs.

4.1. Health monitoring

When the structure changes, the material and load are uncertain. It is therefore critical to consider structural differences when conducting health surveillance. Future projects with similar structural designs may benefit from long-term monitoring data to prevent common problems, make better use of materials and structural capabilities, and reduce long-term risks to the structure. Additionally, it can be utilized to anticipate the onset of weariness, particularly in difficult-to-inspect locations. Numerous respondents also emphasized that in situ monitoring may provide immediate and specific benefits to the continued development of rapidly evolving technologies such as ultra-slim buildings, timber engineering, and the reclamation of industrial brownfield land. However, the long-term effectiveness of the design guidance is unknown for these rapidly evolving technologies. Long-term monitoring information could also help code and standards writers improve and change design specifications [6].

4.2. Intelligent maintenance

Intelligent maintenance is the continuous transmission of health information from distant buildings or facilities to data processing intelligent system through intelligent monitoring equipment. Then data analysis and maintenance suggestions are given by the intelligent system [15]. There are two main types of intelligent maintenance. The first is called vision-driven intelligent maintenance, which is a typically unmanned aerial vehicle (UAV). UAV offers flexibility to practitioners because of the remote controls. Since the UAV can timely complete the detection work without disturbing the normal operation of the building, the monitoring and evaluation methods of the structural health of the building and the process of component maintenance are greatly improved [16]. Figure 1 shows the use of UAV to detect structural cracks. UAV can fly into places that are difficult for people to reach and scan structural surfaces. A

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computer inspector is then used to create a pattern that identifies which cracks appear on the surface. The practitioner only needs to remotely identify the type of crack with a graphic, and then can go to the site to repair it. The other type is intelligent maintenances based on data-driven. They use artificial neural networks to process fuzzy, random and incompatible information and correctly identify damaged areas in the presence of noise.

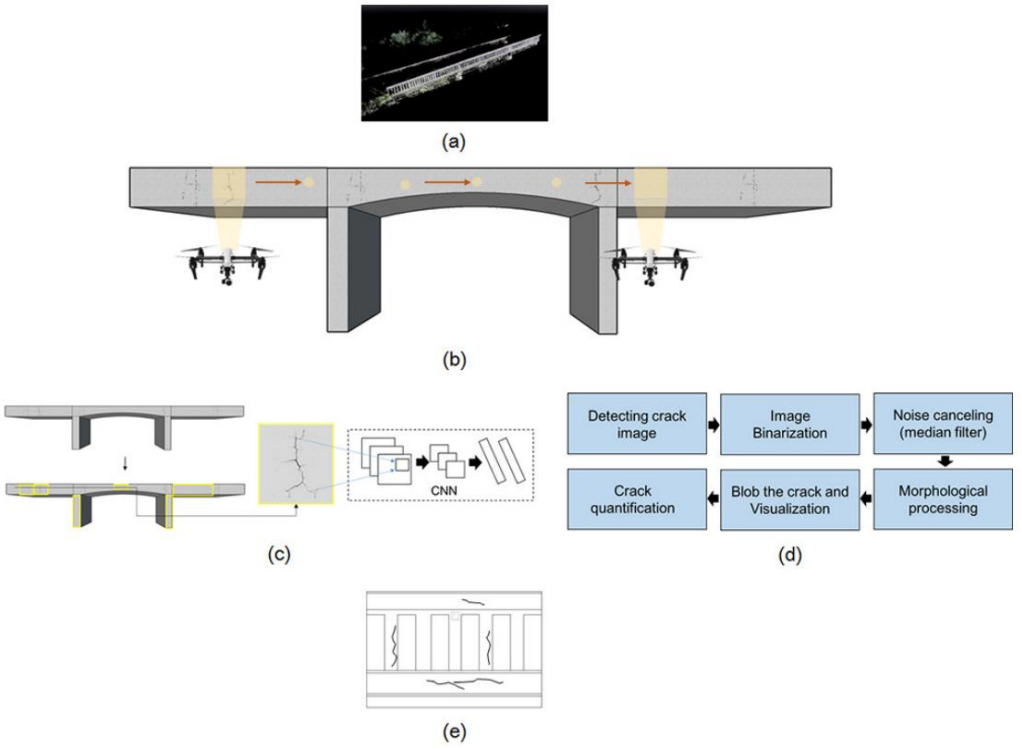

Figure 1. UAV-based crack identification [17].

5. The basic algorithms

Artificial intelligence (AI), machine learning (ML), and deep learning (DL) are the basic algorithms of intelligence and digitization usage in civil engineering. Being the basis of intelligence and digitization in civil engineering, great importance should be attached to them and briefly understand their mechanism. Below is the introduction and overview of AI, ML, and DL.

5.1. Artificial intelligence

Artificial intelligence is the primary use of automation in the civil engineering field. AI define as the process that human cognitive intelligence is involved and will finally be carried out by machines as part of a product or manufacturing system [3]. AI is undoubtedly changing civil engineering to make it follow the development of society. Nowadays fewer and fewer people are willing to do construction work, which is both toilsome and dangerous. This leads to the rise of the salary of workers in construction, it is no more beneficial economically. With the usage of AI, some jobs that originally done by workers can be completed automatically. Artificial intelligence's field of machine learning use computers to analyse data sets and develop models that can be used to solve problems. [18].

5.2. Machine learning

ML use two kinds of technique. The first one is unsupervised learning, and it can find hidden patterns in input data. The second one is supervised learning, in which a model will be trained by human beings on known input and output data, then it can be utilized to predict future outputs. Figure 2 shows the

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category of machine learning and how each of them work. Algorithms is needed for machine learning. The methods and algorithms chosen depend on the quantity and type of data being used, the insights sought for from the data, and the intended use of those insights. ML can either put elements that have the same characteristic in cluster or predict response base on the data it learns. A good example of machine learning is any application where the output you're predicting can take any value in a certain range, like the price of materials.

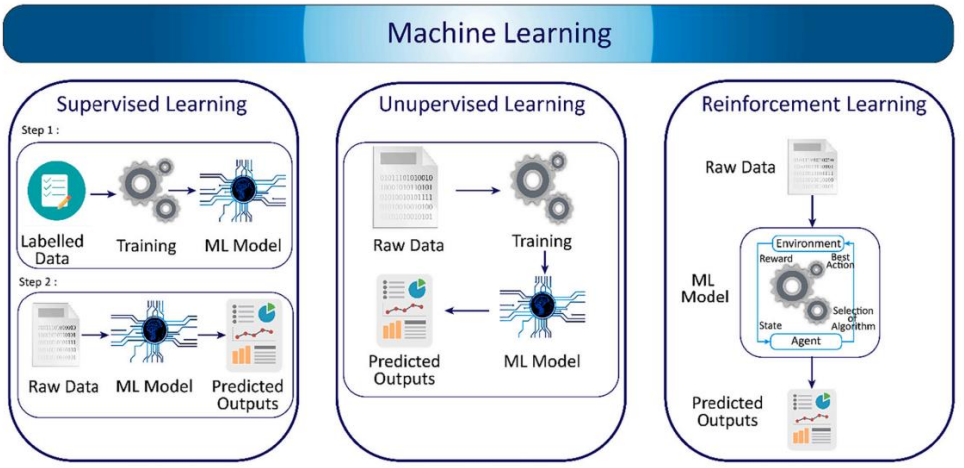

Figure 2. Categorization of ML [18].

5.3. Deep learning

As depicted in Figure 3, a subfield of machine learning is known as deep learning (DL). It is the study of artificial neural networks and other machine learning algorithms with multiple hidden layers. [18]. Humans create network for DL, the connections (like neuron connection) are built during the learning. DL gives computers the ability to mimic human behaviours like thinking and hearing, which helps them solve many challenging pattern recognition issues.

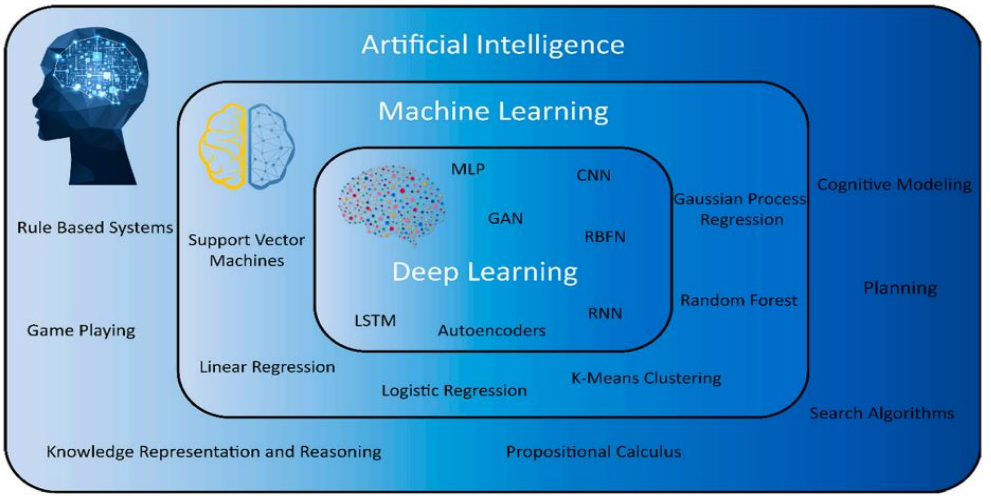

Figure 3. AI, ML, DL, and commonly utilized algorithms domains [18].

6. Conclusion

In recent decades, intellectualization and digitalization have entered every stage of the whole process of civil engineering. This paper studies and discusses the application of intellectualization and digitization in civil engineering from three stages: design stage, construction stage and operation stage. The

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algorithm foundation of intelligent and digital application in civil engineering is summarized, including AI, ML and DL. The results show that intellectualization and digitization have good application prospect in civil engineering field.

In this paper, the various applications of intellectualization and digitalization in civil engineering are briefly listed, and some of them are not specifically studied. With the development of intelligence and digitization, civil engineering is becoming more economical and efficient. However, the current intellectualization and digitization are not perfect. Civil engineering is entering a new era, however, there are still some unavoidable obstacles and drawbacks. Therefore, the development of intelligence and digitalization needs gradual improvement and continuous attempts. Civil engineering will become more intelligent, and it will be possible for dangerous and difficult projects and tasks to be handled entirely by artificial intelligence. Intellectualization and digitalization will make every stage of civil engineering simpler, more accurate and more efficient.

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