Application of Artificial Intelligence Technology in Bridge Construction and Maintenance

Junchen Lu *
SWJTU-Leeds Joint School, Southwest Jiaotong University, Chengdu, China
* Corresponding Author Email: junchenlu@ldy.edu.rs

Abstract. Artificial intelligence (AI) can extract valuable information from analyzing and learning among large amounts of data from bridge. In recent years, the researches and applications of AI in the field of bridge construction and maintenance are gradually increasing with the development of AI. This paper aims to summarize the application of AI in bridge construction and maintenance in recent years. Results show that AI technology can simulate and predict materials and construction scheme and promote the development of material science. In terms of intelligent detection, AI enables automated, efficient, and precise bridge inspection through technologies like visual machines and deep learning. Furthermore, in the realm of intelligent disaster prevention, early warning systems for potential bridge disasters can be achieved via big data analysis and predictive models. In the future, the design, construction and maintenance of Bridges will be increasingly combined with AI technologies, thus making the construction and management of Bridges more information-based and intelligent.

Keywords: Artificial Intelligence; bridge construction; bridge maintenance.

1. Introduction

Artificial intelligence (AI) technology refers to the capacity of computer programs to mimic human intelligence, facilitating the processing and analysis of data, information, and knowledge with the aim of accomplishing predetermined objectives. With the continuous advancement and implementation of AI technology, an increasing number of industries are exploring its integration with traditional sectors. Bridge construction refers to a series of management activities that are planned, organized, coordinated, controlled and supervised in the process of bridge construction. Its purpose is to ensure that the bridge construction can be carried out according to the predetermined plan and standards, in line with the design requirements and quality standards. Civil engineering, as a crucial field in infrastructure construction, is also beginning to investigate the utilization of AI in bridge construction and maintenance.

Currently, AI technology plays a significant role in bridge construction and maintenance, encompassing intelligent materials, detection systems, and disaster prevention measures. These advanced technologies facilitate the design, construction, monitoring, maintenance, and repair of bridges while enhancing efficiency and quality. For instance, leveraging AI capabilities through intelligent detection enables analysis and prediction of bridge structures, materials, and processes to optimize construction plans and enhance safety as well as durability. This paper provides a concise overview of the historical development of bridge construction and maintenance technology followed by an exploration of several applications of AI in these aforementioned areas.

2. The Development of Bridge Construction and Maintenance

The management of modern bridge construction is typically categorized into plan management, technical management, total quality management, quota management, and cost management. The construction of bridge projects adheres to the principles of early completion, ensuring high quality and quantity, prioritizing safety over production while maximizing cost savings. These practices aim to achieve corporate profit growth, prompt return on investment, and enhance enterprises' core competitiveness.

2.1. The Develop Process of Bridge Construction and Maintenance

The earliest bridges were likely simple transitional structures constructed from stone or wood, with maintenance primarily relying on manual inspection and repair. With advancements in technology, more intricate materials like iron and concrete have been utilized for bridge construction, necessitating the implementation of more sophisticated construction and maintenance techniques. Craftsmen traditionally design and build bridges based on their experience and skills, lacking systematic management methods and testing means.

During the Industrial Revolution, the advent of mass-produced steel and concrete resulted in significant breakthroughs in bridge construction technology. Steel bridges and concrete bridges enabled longer, wider, and taller spans to be achieved. In the 18th and 19th centuries, bridge maintenance technologies also underwent continuous improvement as mechanical equipment began to be employed for inspection and upkeep purposes while establishing fundamental principles and norms.

With advancements in structural mechanics, material science, and other related fields, modern bridge construction technology has entered a new phase. The design and construction techniques of novel bridges (such as suspension bridges and cable-stayed bridges) have gained widespread adoption. Simultaneously, there is an increasing recognition of the significance of bridge maintenance, leading to the utilization of regular inspections and high-tech equipment (e.g., drones, sensors) for inspection and maintenance purposes. The implementation of computer-aided design (CAD) and computer-aided construction (CAC) technologies has enhanced the efficiency and accuracy of bridge construction management processes.

In recent years, the rapid development of AI technology has presented new opportunities for bridge management by facilitating data processing, intelligent detection systems, disaster prevention measures, as well as advancements in intelligent materials [1]. Consequently, these applications have improved overall efficiency and quality levels. In summary, the field of bridge construction management has evolved from manual practices to scientific approaches before transitioning into information-based management systems with subsequent integration of AI technologies. As technological progress continues unabatedly, it is expected that bridge construction and maintenance will further evolve towards increased intelligence and efficiency.

2.2. Challenges Faced by Current Bridge Construction and Maintenance

Bridge construction and maintenance are typically conducted in complex engineering environments, such as high altitudes, adverse weather conditions, rivers, or oceans. These environmental conditions significantly augment the difficulty and risk associated with construction activities. Simultaneously, modern bridge projects often entail large-scale operations with intricate technological requirements, while some projects still encounter challenges related to unknown bridge conditions [2]. Consequently, a substantial amount of engineering data and construction resources are necessary for effective resource allocation and schedule control. Some aspects of bridge construction and maintenance involve high-altitude work and the operation of heavy machinery among other high-risk activities; hence safety management assumes paramount importance. Managers must develop an efficient safety management plan that ensures personnel safety through comprehensive risk control measures along with coordinated communication during all stages of construction. Given that multiple parties are involved in bridge construction including designers, contractors, supervision units etc., it is imperative to coordinate their efforts to ensure progress and quality while facilitating effective communication and consultation. Effective resource management coupled with cost control plays a pivotal role in successful bridge construction and maintenance endeavors. Managers need to meticulously plan the deployment of human resources as well as material supplies and equipment to guarantee smooth progress without compromising on project quality or exceeding budgetary constraints. The project also takes into account environmental protection and sustainable development. Designers are required to adhere to environmental regulations and standards in order to minimize the project's ecological footprint.

3. Application of Artificial Intelligence Technology in Bridge Construction Maintenance Management

3.1. Smart Materials

In the mid-1970s, a series of engineering accidents caused by material failure highlighted the inadequacy of existing construction materials and prompted the realization that incorporating self-repairing capabilities could significantly reduce accident rates and maintenance difficulties. Consequently, a novel concept of smart materials emerged. Smart materials represent a new class of substances capable of autonomously responding to environmental changes, such as temperature, pressure, humidity, light, electricity, and magnetic fields by exhibiting corresponding functional adaptations. These responses encompass alterations in shape, hardness, coloration, among others. The widespread utilization of these materials spans various domains including aerospace engineering, mechanical engineering, medical treatment applications as well as construction [3].

Numerous types of smart materials exist including shape memory alloys (SMAs), piezoelectric materials (PEMs), photosensitive materials (PSMs), thermal-responsive substances and more. A shared characteristic among these materials is their ability to modify certain physical or chemical properties in response to specific stimuli. Shape memory alloy stands out as an innovative functional material endowed with remarkable attributes like shape memory effect (SME), superelasticity effect (SEE), elastic modulus variation with temperature and damping property; hence it finds extensive employment within the rapidly advancing field of smart materials and structures [4].

AI can also play a pivotal role in the advancement of materials development, with one such model being the data-driven material informatics model. By leveraging vast amounts of data, machine learning techniques are employed to identify characteristic parameters and conduct data mining (combining artificial intelligence and data) for predicting potential candidate materials. A more stringent definition of machine learning entails a computer code's ability to learn from experience E in order to accomplish task T with improved performance P [5].

Xue et al. employed Bayesian linear regression and other regression models to expedite the development of shape memory alloys with the assistance of machine learning [6]. Based on Xue's research, it is evident that AI can accelerate the advancement process in intelligent material synthesis and integration by leveraging machine learning and deep learning algorithms to analyze extensive material data and performance parameters, thereby aiding researchers in material design and discovery. This approach facilitates property prediction, formulation optimization, and expedites the progress of novel materials.

The adaptive design cycle developed by Xue et al. is illustrated in Fig. 1 [6]. (a) Firstly, the material is characterized using data from previous experiments, physical models, and relevant prior knowledge. This information can be utilized within a machine learning framework to make predictions, including error estimates. The results are then processed using experimental design tools such as global optimization to simultaneously improve the model and discover new materials. These results are recorded in a database and serve as input for the subsequent iteration of the design loop (the green arrows represent the most advanced step-by-step approach utilizing experiments or calculations). (b) (i) Initial alloy experimental datasets with known heat dissipation characteristics or material descriptors are used as inputs for inference models. (ii) The model is trained and cross-validated with these initial alloy datasets to determine the total search space encompassing potential candidates from an unexplored alloy dataset. The trained model from step (ii) is applied to all alloys in step (iii) to predict their properties of interest. (iv) Four candidate materials are designed and selected for synthesis and characterization based on these predictions. (v) For each newly predicted alloy derived through inference and design, four alloys are iteratively chosen for experimentation by expanding the initial dataset by a factor of four.

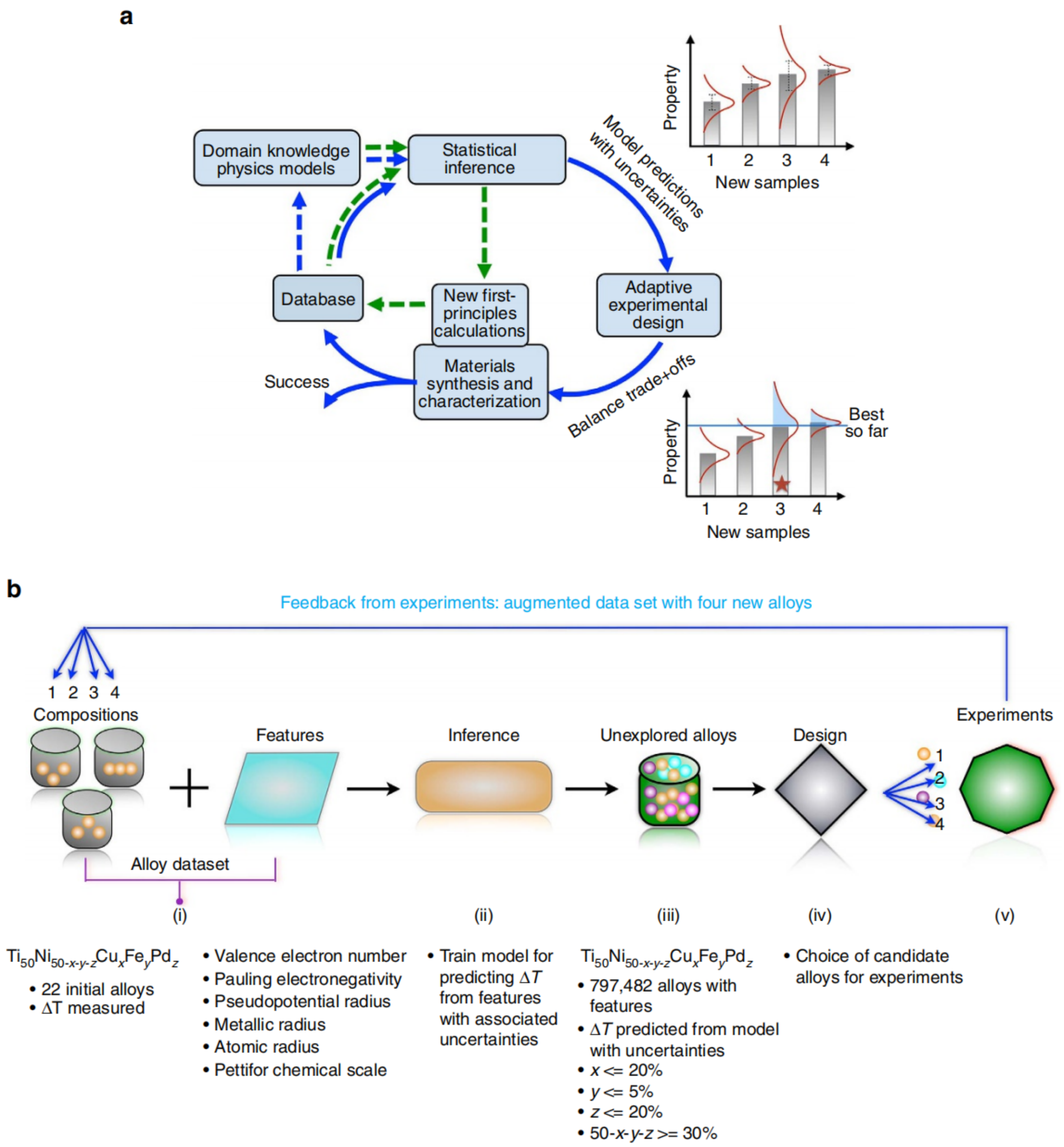

Fig. 1 The adaptive design cycle designed by Xue et al. [6].

As illustrated in Fig. 2, Liang has developed a novel friction sliding bearing system utilizing Shape Memory Alloy (SMA) cables and validated its efficacy in terms of displacement control of bridge upper structures and enhancement of pier curvature ductility [7]. The incorporation of SMA cables enables the bearing to exhibit substantial energy dissipation and damping characteristics during seismic events, thereby mitigating bridge vibrations and improving their seismic performance. Additionally, the shape memory capability of SMA facilitates rapid recovery of the bearing to its initial state post-earthquake, minimizing the impact of aftershocks and prolonging the service life of bridges.

Owing to the exceptional properties inherent in SMA materials, this innovative friction sliding bearing demonstrates remarkable capabilities for energy dissipation and self-recovery, effectively enhancing reliability and safety under extreme conditions encountered by bridges. Moreover, the self-repair feature offered by SMAs significantly reduces post-earthquake maintenance expenses as well as replacement costs for bridges, resulting in overall lower maintenance expenditures.

Therefore, smart materials have exhibited unparalleled advantages in both bridge construction and maintenance domains; meanwhile, intervention from AI can considerably expedite research and development processes while reducing associated costs, facilitating practical implementation of numerous new materials.

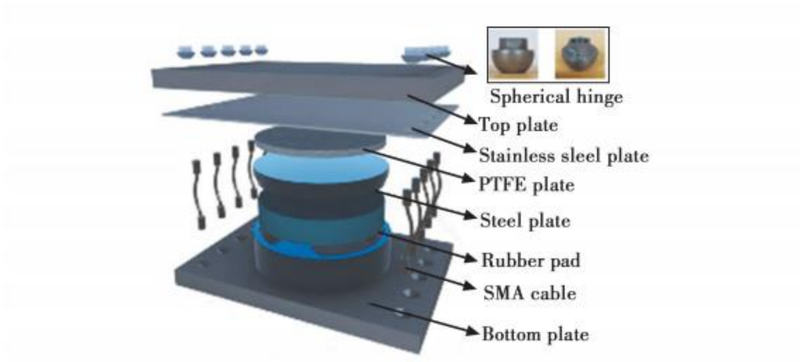

Fig. 2 The newly designed SMA friction sliding bearing system by Liang et al.[7].

3.2. Intelligent Detection

In recent years, significant advancements have been made in the field of AI for bridge inspection. Traditionally, workers had to rely on crane platforms, scaffolding, and even cranes to access hard-to-reach areas of bridges, posing substantial safety risks. Moreover, such extensive and detailed inspections often took more than two weeks.

Perry et al. [8] proposed an intelligent detection system that integrates advanced data analysis tools utilizing computer vision technology and machine learning algorithms to identify common bridge ailments from drone-captured images. Upon receiving the drone imagery, AI techniques such as machine learning and convolutional neural networks can efficiently analyze intricate details regarding the extent of bridge damage.

The technology depicted in Fig. 3 utilizes aircraft photography to collect data, which is then processed through a series of tools to generate three-dimensional point clouds and simulation models using structure-from-motion (SfM) as the foundation for AB-BrIM. Machine learning techniques are employed on the point cloud to create an intelligent model for each bridge element, such as beams, girders, and decks. Subsequently, automated damage/defect detection algorithms analyze the images to identify cracks, spalling, and scaling in concrete, providing quantitative information regarding the location, type, and severity of damage. This extracted damage information is automatically mapped onto each block element of the bridge within AB-BriM. The resulting AB-BrlM incorporates unit damage information along with advanced 3D visualization capabilities that enhance clarity in identifying problematic areas. Consequently, bridge inspectors can efficiently assess the structural condition of existing bridges based on AASHTO and FHWA recommendations.

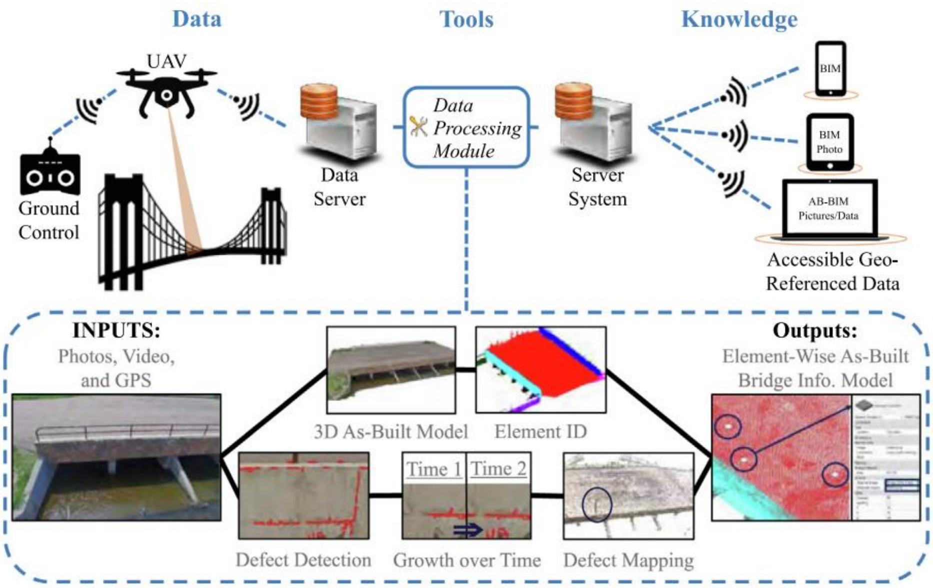

Fig. 3 Intelligent detection system based on unmanned aerial vehicles [8].

The accuracy of vehicle load weight information significantly impacts the maintenance of bridge structures. However, the current available technology, namely bridge dynamic weighing (BWIM) system, involves bulky equipment and high operating costs, making it challenging to be widely adopted.

Therefore, as illustrated in Fig. 4, Zhou et al. [9] proposed a non-contact machine vision-based vehicle weight recognition system for assessing spatial and temporal load distribution on bridges using AI and deep learning algorithms. By analyzing real-time vehicle data captured by fixed cameras, this system directly measures bridge displacement through non-contact machine vision technology and enables rapid evaluation of its state using the rapid retinal critical point method.

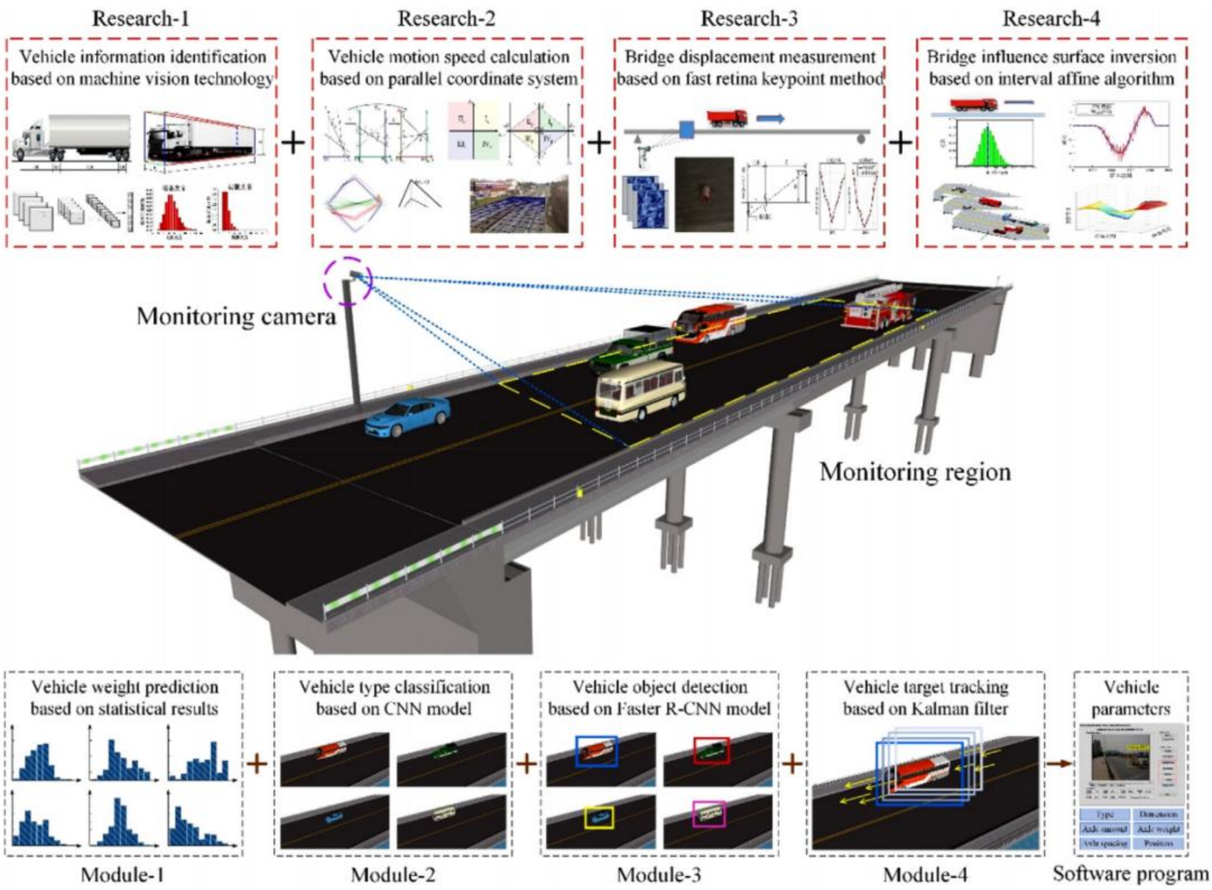

Fig. 4 The vehicle load detection system designed by Zhou et al [9].

3.3. Intelligent Disaster Prevention

With the advancement of bridge technology, the number and popularity of bridges are expanding extensively, while the demands for their service life are increasing. In situations where material upgrades on a large scale are not feasible, it becomes imperative to enhance the disaster prevention capability of bridges. Traditional approaches to disaster prevention in bridges primarily rely on strength fortification (e.g., against debris flow), which suffer from significant limitations. The emergence of intelligent bridge systems has significantly improved bridge detection capabilities. By leveraging new detection technologies, comprehensive data pertaining to various aspects of a bridge can be easily obtained. However, these datasets often remain fragmented big data sets that require integration into meaningful information through AI intervention. The combination of big data analytics with increased computational power and advancements in AI algorithms has laid a solid foundation for empowering AI systems to process vast amounts of data and make accurate decisions aligned with predefined criteria [10].

Debris flow poses substantial threats to both bridges and human safety; therefore, developing an effective flash flood prediction model is crucial. Banihabib proposed a novel hybrid model based on

AI techniques (Bayesian network and support vector-regression particle swarm optimization) integrated with hydrological simulation systems for predicting peak flow rates during debris flow events, which can be effectively employed within debris flow flood warning systems [11].

The artificial intelligence model is illustrated in Fig. 5. Initially, the measured data from hydrological and meteorological stations within the basin are collected to simulate the precipitation process using HEC-HMS model. Subsequently, employing a topographic map at a scale of 1:250,000 and utilizing Arc Hydro tool in ArcGIS software, sub-basins are delineated and a basin model is established through HEC-Geo-HMS program. Building upon this foundation, BN model and SVR-PSO model are developed for predicting sediment content of debris flow. Following identification of debris flow by the artificial intelligence model, predictions for sediment concentration obtained from BN and SVR-PSO models are utilized to modify flood peak flow simulated by HEC-HMS model for accurate prediction of debris flow.

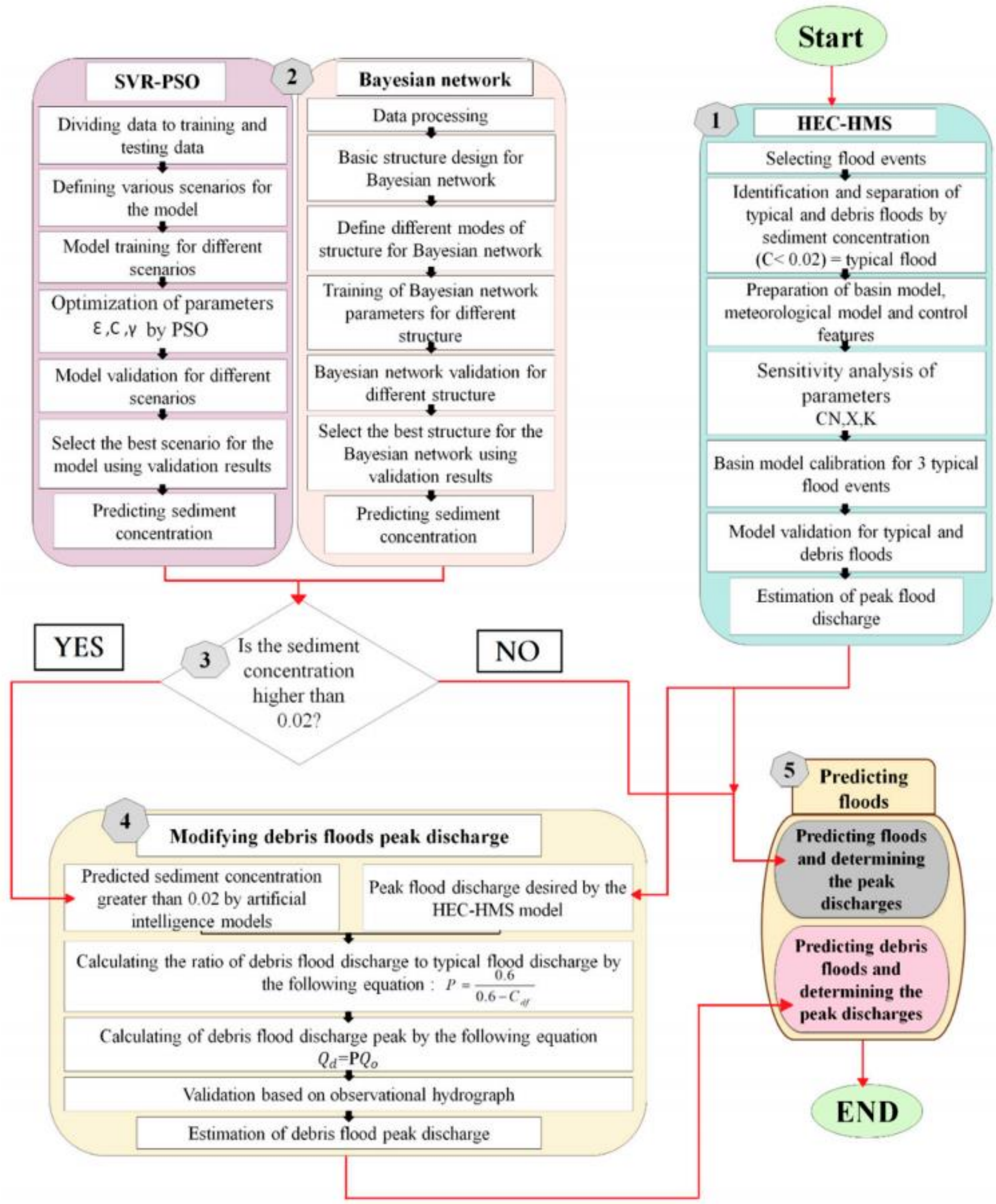

Fig. 5 The research flowchart of a new hybrid model for predicting peak flow of debris flows [11].

4. Conclusion

In recent years, the widespread adoption of AI has revolutionized various domains, including bridge construction and maintenance. The integration of AI technology offers robust support for intelligent detection, material selection, and disaster prevention in bridges, significantly enhancing the efficiency of their construction and upkeep.

The application of AI in materials science has facilitated the development of smart materials, which possess self-healing and adaptive environmental properties that can significantly enhance the durability and safety of bridges. Additionally, through simulation and prediction, AI can assist researchers in selecting optimal construction schemes and materials.

In terms of intelligent inspection, AI enables automated, efficient, and accurate bridge inspection through the utilization of vision machines, deep learning algorithms, and other advanced technologies. For instance, unmanned aerial vehicles (UAVs) can be equipped with high-definition cameras and lidar sensors to conduct regular inspections of bridges. By leveraging deep learning algorithms, these inspections can promptly identify any structural gaps in the bridge. Furthermore, the analysis of inspection data is automated to provide maintenance recommendations that enhance detection accuracy.

Artificial intelligence (AI) can facilitate early detection of potential disaster events on bridges through comprehensive analysis of big data and predictive models. For instance, by examining historical meteorological records and bridge construction data, the anticipated impact of floods, earthquakes, and other natural calamities on bridges can be forecasted accurately, enabling timely implementation of precautionary measures.

In summary, the application of AI in intelligent detection, intelligent materials, and intelligent disaster prevention for bridge construction and maintenance not only enhances operational efficiency and reduces costs but also enhances the safety and durability of bridges. The widespread adoption of bridge informatization, intelligence, and AI technology is expected to be a prevailing trend.

References

[1] Zhao Tianqi, Gou Hongye, Chen Xuanying, et al. Research progress of bridge informatization and Intelligent Bridge in 2020. Journal of Civil and Environmental Engineering, 2021, 43(S1): 268-279.

[2] Xia Zhongli. Problems existing in Road and bridge maintenance and discussion on preventive measures. Chinese Science and Technology Journal Database (full-text edition) Engineering Technology, 2016, (12): 00012.

[3] Li Ruijun, Niu Chaoran. Application of smart materials in bridge engineering. Municipal Technology, 2010, (4): 145-147.

[4] Jia Wenjie, Ding Hanshan. Research on intelligent prestressed bridge system based on shape memory alloy materials. Modern Transportation Technology, 2007, 4(6): 45-48.

[5] Mitchell T. Machine learning and data mining. Communications of the ACM, 1999, 42(11): 30-36.

[6] Xue D, Balachandran P V, Hogden J, et al. Accelerated search for materials with targeted properties by adaptive design. Nature Communications, 2016, 7: 11241.

[7] Liang D, Zheng Y, Fang C, et al. Shape memory alloy (SMA) cable-controlled sliding bearings: Development, testing and system behavior. Smart Materials and Structures, 2020, 29 (8): 085006.

[8] Perry B J, Guo Y, Atadero R, et al. Streamlined bridge inspection system utilizing unmanned aerial vehicles (UAVs) and machine learning. Measurement, 2020, 164: 108048.

[9] Zhou Y, Pei Y, Li Z, et al. Vehicle weight identification system for spatiotemporal load distribution on bridges based on non-contact machine vision technology and deep learning algorithms. Measurement, 2020, 159: 107801.

[10] Yuan Wancheng, Wang Sijie, Li Huaifeng, et al. Development of seismic intelligence and toughness of Bridges. China Journal of Highway and Transportation, 2021, 34(2): 98.

[11] Banihabib M E, Jurik L, Kazemi M S, et al. A hybrid intelligence model for the prediction of the peak flow of debris floods. Water, 2020, 12(8): 2246.