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IMPLEMENTATION OF METHODOLOGICAL AND NORMATIVE BASES BASED ON ARTIFICIAL INTELLIGENCE (AI) FOR BRIDGE HEALTH MONITORING IN PERU.

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Key words: bridge health monitoring (BHM), artificial intelligence (AI), bridge codes, damage detection, international standards, damage features.

Abstract. The deficient updating of Bridge Structural Health Monitoring (BHM) standards in Latin America has resulted in a deteriorated road network with low trafficability services and economic deficiency. Most bridges have suffered damage and collapse due to recurrent natural disasters, poor quality materials, inadequate structural calculations and the traditional approach to bridge inspection and maintenance. The majority of bridge collapses in Peru have generated a need to implement lineaments to help improve the monitoring of these infrastructures. In this sense, this research establishes the methodological bases using the BHM lineaments, since it shows a progressive technological advance in developed countries (Europe, Asia, USA). International standards (EUROCODE, JT/T 1037-2022, AASHTO) and research on bridge damage identification methods are compiled. Additionally, the types of devices that generate a quantity of data to be processed through the use of modern algorithms are described. For example, Artificial Intelligence (AI) is used for automation of solutions, correct location of sensors, early damage detection and decision making for maintenance and operation of bridges. In conclusion, these lineaments are selected according to the reality of the country, thus generating a vast database of research related to BHM to finally generate a guide of specifications that will serve for decision making for future bridge monitoring in Peru.

1 INTRODUCTION

Bridges are critical assets that provide safety, reliability and functionality to transportation networks[1] in order to interconnect cities and improve a country's economy. In addition, there are factors that accelerate structural deterioration such as [2, 3]: natural hazards that have left 449 bridges collapsed in 2017 in Peru as a result of the El Niño phenomenon. [4], man-made ones such as the collapse of Line 12 of the Mexico City Metro [5] and the natural behavior of the structure that characterizes vibrations or frequencies that serve to diagnose damage [6–9]. Therefore, recent studies worldwide focus on life cycle analysis encompassing the maintenance phase and implementation of bridge monitoring strategies. [10, 11]. Beside, BHM research defines the study of the structural health condition of bridges through modern devices, Big Data (BD) processing algorithms, decision making and solutions adding AI in the automation process. [12–14]. In [15] the BHM objectives are to detect, locate, quantify and diagnose damage. In [16] applies deep learning as an AI tool for monitoring arch and cable-stayed bridges comparing the accuracy of damage detection. The implementation of BHM regulations in China

[17] , Italy [18] and USA [19] propose technological monitoring. While in Latin America the regulations are of traditional monitoring [20–22]. Therefore, to implement the BHM it is necessary to understand the methodology through a technological monitoring guide verifying the intervention of AI within the process. In [23] proposes ethical guidelines for the use of AI. As there are few AI regulations worldwide. We propose guidelines for the use of AI within the BHM prioritizing the part of sensor positioning, processing and data analysis maintaining the ethics exposed in [23–25]. These bases will serve for future AI research applied to bridge monitoring.

2 IMPLEMENTATIONS OF AI-BASED GUIDELINES IN PERU

2.1 Significance of implementing AI guidelines in BHM

The implementation ofAI regulations in BHM is of vital importance to ensure the safety and durability of bridges. In Peru, there is currently a bridge inspection guideline constituted by the Ministry of Transport and Communications (MTC) with a traditional approach [21]. Worldwide, the application of BHM is evolving in devices and applied to AI [26, 27]. On the other hand, in Latin America, not having guidelines there are problems such as: choosing unnecessary instrumentation and inadequate hardware, obtaining data with too much noise and incorrect data processing [17], so it is important to have AI guidelines within the BHM guide to standardize the use, propose and suggest methods according to the characteristic of the bridge. Furthermore, in [28] successfully predicts damage scenarios with AI algorithms. In [29] mentions that AI will become part of our daily life through the use in different specialties as it was done with the Internet and social networks. Standards ensure that AI is used responsibly and affectively, maximizing its benefits while minimizing its risks [24, 30]. Therefore, without clear standards, the accuracy and reliability of these algorithms may be compromised to results in damage detection failure and in turn structural failures.

2.2 General bridge monitoring guide

The present research proposes a general methodology to implement a guide in BHM, as shown in Figure 1. In [21], traditional monitoring by means of routine and periodic inspections and prevailing data collection by means of visual inspections are presented. In [18] proposes Structural Health Monitoring (SHM) in regular and permanent inspections implementing sensors. Therefore, it is submitted within the BHM normative research for Peru. In addition, the progress of permanent monitoring has developed automation through AI. In [17] shows the BHM standards and the management of data obtained by monitoring devices. Therefore, the BHM guide is subdivided into two sections raising the obtaining of traditional inspection with technological monitoring.

The first section is called **"Obtaining historical data"**. It defines the typology, material, geometric and physical characteristics of bridges in Peru. In [31] they propose the classification of bridges according to their use and purpose of application (12 categorizations). In [21] they emphasize the sections of arch, beam and cable-stayed bridges. In [32] they report truss bridges for permanent and temporary use. In addition, the existence of the "Continental" bridge, known for being the longest in the country, includes suspension bridges in the study. Therefore, the typology of beam, truss, arch, cable-stayed and suspension bridges is proposed within the guide.

On the other hand, the constitution of materials, in [33] gives relevance to the monitoring of cable-stayed bridges through the use of devices for the study of the resistance in steel stays. Furthermore, in [34] he proposes and describes materials such as concrete, steel, wood and masonry according to the Federal Highway Administration (FHA) (Federal Highway Administration). While the MTC specifies the use of stone, wood, ropes, iron, steel, reinforced concrete, prestressed concrete and composite materials constituted in bridges[31]. When analyzing the condition of bridges, in [32] steel and reinforced concrete are the most used materials in Peru. Therefore, the study is proposed under three types of materials: steel, stone and reinforced concrete. As for the study of the pathologies and frequent damages of the bridge, they are carried out under the proposed typology and material [35] propuestos. Finally, in [36] the temperature influences the performance of integrated transducers, therefore, physical parameters such as humidity and temperature are studied, which generate variance in the data obtained by the sensors.

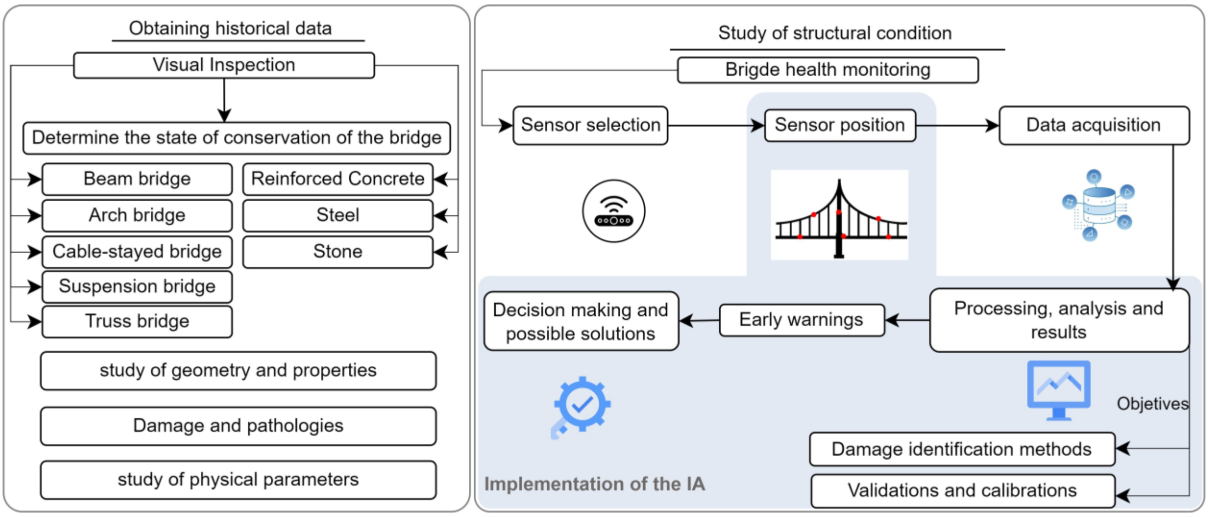

Figure 1: BHM guide outline.

For the second section **"Study of the structural condition"** the emphasis is on the BHM proposal. When obtaining the Historical Data, sensors are selected and positioned within the system. For example, for steel bridges, two groups of sensors are proposed to obtain the local and global response through nondestructive testing techniques [37, 38]. In [36] an improvement to the sensors for the study of load effects and temperature variation is presented, improving the accuracy of the data. As for the instrumentations such as sensors and other monitoring devices require an extensive data acquisition and storage system, therefore, in [39] the improvement of the accuracy of the data obtained by AI algorithms is studied. In addition, the BD management techniques proposed in [11, 13] assign a flow of steps which are: preprocessing, integration, data characterization, pattern recognition and visualization of the overall data. In [12] they propose damage identification methods by classifying beam, truss, arch, cable-stayed and suspension bridges. Regarding the verification of results, in [1] propose specific conditions for the calibration and validation of railway bridges improving maintenance decision making by means of Petri nets. On the other hand, in [40] formulate successive strategies for the improvement of maintenance accuracy.

Finally, by means of the scheme presented in Figure 1, the intervention of the AI in the shaded phases is identified. Research suggests implementing AI models from the data preprocessing stage [41, 42]. On the other hand, [40] proposes an automation and constant updating of the model from the processing with new data obtained. Therefore, the intervention of IA is considered from the monitoring instrumentation phase to propose guidelines covering the phases indicated.

2.3 Implementation of IA standards

Recent research in BHM has applied AI by improving BD processing and validation techniques using algorithms [6, 43]. Thus machine learning (ML) and deep learning (DL) are developed within BHM [13, 44]. Such algorithms have shown similar results in damage detection of a steel bridge [37]. In [45] the process of automated 3D inspection using Unmanned Aerial Vehicles (UAV) of 30 bridges in USA and Japan with an accuracy improvement of up to 85.3 %. While in [9] studies unsupervised ML vibration-based damage indicators to verify the variation of environmental conditions. In [46] the use of AI in BHM has brought benefits, challenges, new approaches and recent advances in technology. A clear example is the use of robots for monitoring steel bridges [47]. The use of sensors generally brings too much digital information which can create insufficiency in BD processing, therefore in the face of computational insufficiency supervised or unsupervised algorithms are employed to obtain more accurate results [13]. In order to propose AI models, information from application cases is collected. En [48] automated crack inspection with a Convolutional Neural Network (CNN) was performed on the Skodsborg bridge using UAV. In [37] studies local and global damage detection in Hell Bridge Test Arena with triaxial accelerometers. In [43] predicts failures of the Railroad line VDE 8 bridge using Artificial Neural Networks (ANN). In [49] automated location with the use of CNN in Quisi bridge using strain sensors. Consequently, AI models are proposed according to the objectivity of results as shown in Figure 2 in "AI model creation". In addition, the scheme starts with the positioning of sensors known as "input" since they are the input data needed for the creation of an AI model. Data processing is necessary for noise removal due to physical parameter effects. Testing and validation are necessary to ratify that the model performs its function without failure to implement and monitor the bridge. In addition, in order for the model to continue to develop accuracy, maintenance and updating of the model is proposed, so it will have to go through the above-mentioned items to put it back into operation. To implement AI standards applied to the BHM, the regulations that specify traditional bridge monitoring are taken into account to see the development and evolution of the BHM.

Therefore, Table 1 gathers the regulations according to the continent for three types of items: first, for traditional bridge monitoring where it is worth noting that a part of the Eurocode and AASHTO stipulate visual inspection as a primary part of the BHM process and for the creation of the overall inventory; second, BHM guidelines are being developed in greater detail in China which implements standards in its regions and provinces [50], while Russia specifies BHM management for data processing [51]; finally, the application of laws in IA are mostly encompassed to the ethics of information, processing and data collection [52]. Globally, continents propose ethical guidelines and reliability characteristics for the use of IA [30]. Therefore, guidelines are proposed for each phase in Figure 2. The guidelines in red are of primary importance covering all study phases, those in blue cover one respective phase and may be variable to act in another phase, and those in yellow cover one, two, or all phases.

Table 1: Traditional monotoring regulations, BHM guidelines and AI laws.

	TRADITIONAL MONITORING GUIDES	BHM GUIDES	NORMATIVES AI
Asia	India [53]	China [54], Japan[55] and Russian [51]	Plan to 2023 China[23] and Russian [51]
Europe	Part of section of Eurocode [56]	Italy [18], Sweden[57] and Eurocode [58]	European Commission AI Ethics [24]
North America	Costa Rica [59] and USA [60]	USA [19] and Mexico [61]	USA through its states and cities [62]
South America	Argentina [22], Colombia [20] and Perú [21]	Peru and Chile are mentioned in the manual.	Law on the use of AI in Peru [63]
Oceania		New Zealand [64]	Australia [65]

The first guideline covers **"security"**. In [52] the AI must be robust, secure throughout its life cycle and function properly without risks. In [66] proposes AI ethics in the scientific domain and in real-world applications. But in BHM there are types of AI, in [11] proposes a Taiwan Bridge Management System (TBMS) implemented for monitoring by BD techniques in a constantly updated bridge network. While [17] exposes China's guidelines on data acquisition and is still in the process of creating regulations on sensor data management. Therefore, the security item proposes the care in the processing and storage of the BD for reliable results and future research, in addition, the AI should comply with the guidelines of redundancy, protection, supervision, emergency protocol, transparency and explainability to certify the security of the model. For the second guideline, the input data also known as "input" involved in the creation and application of the AI, "**redundancy**" is proposed. In [43] presents a solution to the possible failures in the sensor network in the monitoring of the Railroad line VDE 8 bridge. To improve the positioning of sensors, in [67] creates an efficient algorithm for the improvement of the wireless sensor network. In [68] the degree of redundancy according to the position and the level of service that the sensor has. Therefore, redundancy is considered an important parameter within the sensor network because if one sensor fails, another one can take over the task of obtaining the missing data in order not to damage the algorithm or the AI model. The third line of **"protection"** covers Data Processing. In [69] studies the field of information systems and data science encompassing AI ethics. In [70] it proposes a provision of laws on data according to the scientific, personal or governmental purpose. In [25] recommends good practices for data management. Thus, responsibility is proposed from the moment of data acquisition to the end of the validation process of the AI model in order not to manipulate the results. For the fourth guideline, **"supervision"** is proposed from the beginning of the creation of the AI model to the testing and validation phase. In [71] proposes supervision to evaluate the performance of the AI life cycle. In [72] he indicates the presence of human operators to ensure the safety of automation. Furthermore, in [69] supervision assumes responsibility for the decision to automate the AI model. Therefore, at the time of validating the model, it should be monitored before, during and after its application. In the remote probability of failure of the AI model, the fifth guideline of **"emergency protocol**" should be implemented. In [52] proposes a plan where the characteristics of the AI model and methods that reverse, remedy and allow a repair in case of damage are highlighted. Therefore, it is proposed to have a contingency plan that includes a backup model ready to be implemented in case the main model fails.

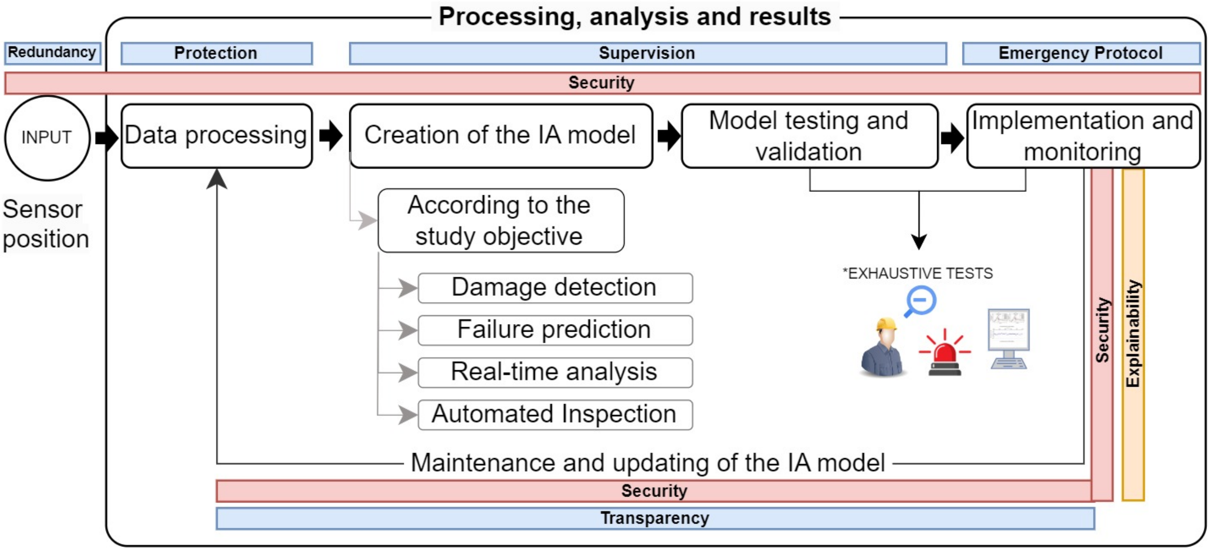

Figure 2: AI guidelines within the BHM.

For the sixth guideline, **"Transparency"**, works in conjunction with explainability. In [52] he proposes fluid communication by exposing the benefits, harms and possible outcomes that allow humans to make informed decisions. In [73] he discusses the importance of explainability and clarity in ML. Thus, transparency involves understanding how the model makes decisions based on the “input” to generate greater confidence in its predictions and recommendations. Finally, **"explainability"** is proposed as a connection between the emergence protocol and transparency, but it can encompass all phases because it generates greater security in the process. In [52] explains that the AI model must be exposed to external algorithmic auditing bodies to ensure understanding, communication and functionality while guaranteeing security. In addition, there are techniques to help the interpretation of AI models such as Local Interpretable Model Agnostic Explanations (LIME)[74]. Therefore, the monitoring of a model must be expressed through explainability in order to be able to act quickly in the emergency plan and in the update phase.

3 CHALLENGES OF IMPLEMENTING GUIDELINES

AI guidelines have recently been employed in the BHM, these bring challenges and problems, these may be: First, DB collection and processing may be impaired by the physical parameters and accessibility of the bridge. Second, transparency and explainability of AI models are crucial to generating confidence in predictions but may be difficult to achieve with more complex models such as CNNs and black boxes [75]. Third, implementing AI in this context requires close collaboration between AI experts and structural engineers, which can be challenging due to differences in language and training. Finally, the AI must be able to adapt and learn from new data as it is collected, which requires continuous monitoring and maintenance of the model.

These challenges underscore the importance of a careful but thoughtful approach to execution that can bring favorable results. China has shown progressive advancement of the AI standards plan [23] and BHM guidelines that revealed a reduction in the number of dangerous bridges [17]. Similarly, Russia shows a network of regulations in each process of bridge monitoring [51]. Therefore, it is important to take the time to update and promote standards in the field of civil engineering encompassing AI.

4 CONCLUSIONS

- The methodology of the BHM guide follows the guidelines of China, Russia and USA in the monitoring of bridges proposing the "Obtaining historical data" for the background and "Structural condition study" for the technological monitoring.
- The IA guidelines within the guide were investigated according to the regulations of the European Union, Australia and China, which show a progressive advance in the ethics and research of IA models.
- The present research proposes the guidelines of: safety, redundancy, protection, supervision, emergency protocol, transparency and explainability oriented to the proposed phases within the BHM methodology in order to ensure the applicability of IA. In conclusion, these guidelines are selected according to the reality of the country for future bridge monitoring decisions.

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