Quantitative and Qualitative Analysis of Harmony Search Algorithm in Geomechanics and its Applications

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Abstract. The harmony search (HS) algorithm is one of the meta-heuristic algorithms that was inspired by the concept of the musical process with the aim of harmony, to achieve the best solution was introduced. In comparison with other meta-heuristic algorithms, one of the most significant characteristics of this algorithm that has increased the flexibility of the algorithm in search of solution spaces is the use of all the solutions in its memory. The literature review shows that according to the high efficiency of the harmony search algorithm, it has been widely used in various sciences in recent years. Hence, the main purpose of this study is to review the applications of the harmony search algorithm in geomechanics that is a significant research topic in the engineering and aca-demic sectors. For this purpose, articles of geomechanics including the two main disciplines namely soil mechanics and rock mechanics are evaluated from 2011 to 2021. Also, two qualitative and quantitative investigations are applied to review articles based on the Web of Science (WOS) platform. This study indicates that the harmony search algorithm can be applied as a powerful tool for modeling some problems involved in geomechanics.

Keywords: Harmony search algorithm, Geomechanics, Rock mechanics, Soil mechanics, Literature review, WOS.

1 Introduction

Geomechanics is the science of studying the mechanical behavior of soil and rock. Soil mechanics and rock mechanics are the two main branches of geomechanics that are used in a wide range of projects of theoretical and practical including engineering geology, mining, petroleum, and civil engineering. In many construction and operation

projects, the geomechanical study of projects plays a key role in the success of a project, therefore, insufficient attention to this issue can lead to irreparable loss of life, environment, and fi-nance. Extensive studies have been conducted in various branches of geomechanics such as Rock Mechanics [1-11], Geotechnics [12-17], and Tunneling and Underground spaces [18-24]. Li et al., (2020) introduced a forecast process of the uniaxial compressive strength by developing the Group method of data handling algorithm. Their results ap-proved that the proposed GMDH model can be considered a robust prediction system [25]. Ching et al., (2021) evaluated the deformation modulus of the rock mass. They used the four methods to determine such modulus. Based on their results, the hierarchical Bayesian model was a reliable model in comparison with other models [26]. Bagheri and Rezania evaluated the geological and geotechnical properties of London clay from the Isle of Sheppey. Their study integrates the earlier and recent studies with the aim to develop the current knowledge of the geotechnical properties of this stiff clay from the east of the Lon-don basin [27]. The unconfined compressive strength of clay material mixed with recycled additive was predicted by Al-Bared et al., (2021). They designed a series of laboratory tests and then, they used two hybrid intelligence systems. The results obtained demonstrated the effectiveness of both hybrid predictive models [28]. Fardonbe et al., (2020) investigated rockburst hazards using two robust clustering techniques. They provided some suggestions to reduce the effect of rockburst by optimizing the diameter and shape of the under-ground openings [29]. Geological conditions and clogging of tunneling were investigated by Bai et al., (2021). They used machine learning-based approaches and the results obtained indicated that there was suitable compliance between measurements and the ap-plication of machine learning-based approaches [30]. Pham et al., (2021) have focused on presenting new models for classification of soils based on laboratory tests. They applied the three artificial intelligence techniques namely Adaboost, Tree and ANN. In addition, 440 samples of the real project were applied to develop and present the proposed method-ology, and this data included clay content, moisture content, specific gravity, void ratio, plastic, and liquid limit parameters. Finally, their proposed methodology could achieve highly acceptable degrees of accuracy and also it could decrease the cost of projects [31].

A review of the previous literature reveals that various approaches and techniques have been used in the study, evaluation, analysis of research related to geomechanical problems. Also, in recent years, the use of artificial intelligence methods has been relatively widely used in this research. Therefore, the purpose of this study is to review and analyze the qualities and quantities of the articles related to the application of harmony search algorithm as one of the practical and robust algorithms in the field of artificial intelligence in the branches of geomechanics during the last decade. It should be noted that all documents are reviewed from the Science Citation Index (SCI), which is achieved by subscription from the ISI, Web of Science, Philadelphia, PA, USA.

2 Methodology

Literature review plays a key role in assessing the body of knowledge to identify potential research gaps and highlight their boundaries [32-33]. Therefore, qualitative and quantitative analysis are presented by reviewing all documents and articles related to the branches of geomechanics and harmony search algorithm based on the Web of Science (WOS) platform in this study. For this purpose, firstly a review of the application of the harmony search algorithm is performed in all disciplines, and then a review of articles and other documents related to the application of the harmony search algorithm in geo-mechanics is reviewed. It should be noted that the Harmony Search Algorithm was introduced in 2001 and We wanted to show that after a decade of introducing the algorithm, how much is the participation of this algorithm in scientific issues, therefore this study will focus on published documents from the January of 2011 to the July of 2021.

2.1 Quantitative Analysis

The SCI is systematically investigated during the quantitative analysis from 2011 to the July of 2021. As mentioned before, First, a quantitative review of the application of the HS algorithm in all disciplines is done. Then a quantitative review of the application of the HS algorithm in geomechanical branches is conducted. For searching in the second quantitative review, the set of keyword combinations are determined, such as " HS algorithm AND Rock Mechanics", " HS algorithm AND Rock Breakage", " HS algorithm AND Ornamental Stone", " HS algorithm AND Rock Drilling", " HS algorithm AND Land-slide", " HS algorithm AND Geotechnics", "HS algorithm AND Soil Mechanics", "HS algorithm AND Foundations", " HS algorithm AND Flyrock", " HS algorithm AND Tunneling" and " HS algorithm AND Slope Stability". It should be noted that this search was selected only in the topic to focus more on articles. The parameters that were analyzed included authorship, patterns of international collaboration, number of times cited, reprint author's address, and reprint author's address. Citation analysis was conducted according to the impact factor which is determined by the Journal Citation Reports (JCR) and on Citations per Publications (CPP), which are applied to evaluate the impact of a journal relative to all fields.

2.2 Qualitative Analysis

The historical method is applied for qualitative analysis that is rich and complex. In this type of analysis, investigation of the places, times, and contexts in which events occur and develop to be useful for better understanding of issues. In this study, a qualitative study of the application of the HS algorithm in geomechanical branches in the last ten years is performed. Based on the results, a summary of the possibility of using this algorithm in future work is given.

3 Harmony Search (HS) algorithm

Meta-heuristic algorithms are one of the most powerful tools for solving optimization problems and also increase the ability to find high-precision solutions to difficult optimization problems [34-40]. The harmony search algorithm is one of the most practical me-ta-heuristic algorithms, inspired by the process of making music by a composer to harmonize a piece of music [41-42]. The harmony search algorithm was introduced in 2001, and it has been used successfully in a wide range of engineering and scientific issues. Search harmony algorithm has unique features that have made this algorithm one of the most widely used optimization algorithms in recent years in various problems, including the flexibility of the algorithm in search of better solutions for discrete and continuous optimization problems, low mathematical calculations, and low parameters [43-44].

4 Review of Application of HS

4.1 Quantitative evaluation of Publications and Citations

According to the data obtained from the web of science for a period of ten years from January 2011 to August 2021, 1313 documents were determined. The distribution of the number of publications per year is shown in Figure 2. According to the distribution of publications in Figure 2, it is clear that most of the number of publications in 2016 was 169 documents. Also, Harmony Search in the title in 2021 has had 51 documents in 7 months since the beginning of the year. Based on Figure 1 , it can be seen that there is an approximate decrease in the number of documents published since 2016, which one of the most important reasons is the introduction of a wide range of meta-heuristic optimization algorithms and the willingness of researchers to use the new titles in their researches during this period. Although the number of published documents has fluctuated over the past 10 years, in most of these years more than 100 articles have been published each year that Harmony Search was in their titles, indicating the algorithm's place in the field of scientific publishing.

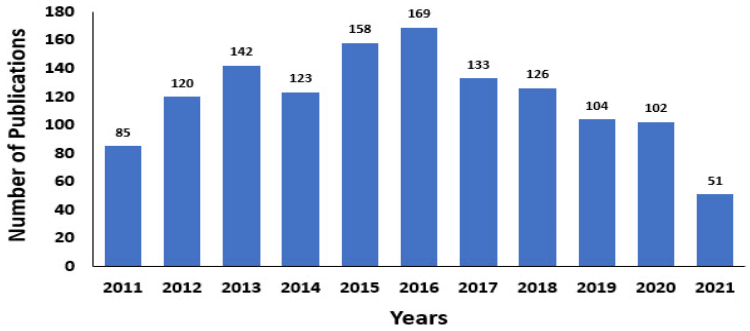

Fig. 1. Number of published documents per each year from January 2011 to August 2021.

4.2 Qualitative Analysis

The top authors and the number of published papers in the top ten countries in the field of harmony search algorithm are shown in Table 1. The largest number of documents published in this period belonged to Geem with 52 documents. Also, Al-Betar, Del Ser, Gao, Khader, and Bekdas were authors with over 20 papers on the top authors' list. Among the countries, China ranks first with the release of 336 documents, and India and Iran were the next countries in producing content based on the Harmony search algorithm with 230 and 186 documents, respectively. At the end of the top ten countries list, Jordan and Mexico, with 32 print documents have an equal share with each other in printing the documents which were related to Harmony Search Algorithm.

Table 1. Top ten Authors and Countries from January 2011 to August 2021.

Top ten Countries			**Top ten Authors**		
% of 1,313	**Record Count**	**Countries**	**% of 1,313**	**Record Count**	**Authors**
25.57	336	CHINA	3.95	52	Geem ZW
17.5	230	INDIA	1.9	25	Al-betar MA
14.15	186	IRAN	1.59	21	Del Ser J
7.68	101	SOUTH KOREA	1.59	21	Gao LQ
7	92	MALAYSIA	1.59	21	Khader AT
5.02	66	TURKEY	1.52	20	Bekdas G
4.94	65	USA	1.44	19	Awadallah MA
2.81	37	AUSTRALIA	1.44	19	Kim JH
2.43	32	JORDAN	1.44	19	Li S
2.43	32	MEXICO	1.44	19	Pan QK

5 Review of Application of HS in Geomechanics

In the previous sections, a review of the position of the Harmony Search Algorithm in various disciplines over the past decade from January 2011 to August 2021 was conduct-ed that the results showed the appropriate process of citations as well as the ability and efficiency of the algorithm in solving various problems in different countries of the world. Although the harmony search algorithm had a significant share in many disciplines, in some fields, especially geomechanics, it had a much smaller share that one of

the reasons could be the desire of more geomechanical researchers to solve related problems in this field using classical methods or relatively older algorithms. However, this review has shown that in recent years, the innovative use of this algorithm in various branches of geomechanics has led to articles with suitable citations. Therefore, on the one hand, given the wide and variety of applications of Geomechanics in many fields such as tunneling, dam construction, drilling, civil engineering structures, and petroleum engineering, and, on the other hand, appropriate trend of increasing citations in documents related to the harmony search algorithm, It can be a good opportunity for researchers in the field of geomechanics to not only use a new and innovative method in their research but also in-crease the chances of growing citations. Some of which will be discussed in the next section. It should be noted that in this review to focus more on the application of the harmony search algorithm in various subjects, the harmony search algorithm with other related words, were searched only in the title of documents.

5.1 Review the top-cited papers in Rock mechanics

In the field of tunneling as a subset of geomechanics, the study of Mikaeil et al., (2016) gained the highest citations. In their study, the harmony search algorithm was applied for optimizing the K-Means clustering algorithm to investigate the geological hazards in a tunneling project. As a result, a comparison was made between the obtained results from data analysis using hybridization of K-means and harmony search algorithm with the observed results, and this comparison showed that harmony search algorithm had the high efficiency and performance to optimize K-means algorithm for modeling some tunneling problems [45]. In another study, Mikaeil et al., (2019) used the harmony search algorithm for modeling a problem involved in rock mechanics engineering. They used the hybridization of K-means and harmony search algorithm to evaluate the performance of diamond wire saw by rock characteristics and controlled parameters related to characteristics of the cutting machine and operational parameters. Their results obtained showed that hybridization of K-means and harmony search algorithm was a reliable system modeling technique. Figure 6 shows the minimum cost per iteration in process of HAS- K-means optimization. This study could achieve 16 citations according to the WOS platform [46].

In another problem in the field of rock mechanics, Hasanipanah et al. (2020) published in the journal of Engineering with Computer that used the dynamical harmony search algorithm in the training of artificial neural networks. This article with 15 citations on the WOS platform is one of the most cited articles in this field. In fact, they used the ANN-adaptive dynamical harmony search algorithm to predicted undesirable and inevitable effects of blasting in rock excavation namely flyrock. The results of this novel hybrid ANN-adaptive dynamical harmony search algorithm had higher degrees of accuracy and robustness compared to other used methods [47].

5.2 Review the top-cited papers in Soil mechanics

Cheng et al., (2011) carried out an investigation into using two improved harmony search methods in geotechnical problems that were published in the Journal of

Mechanics from Oxford University Press. The efficiency of the proposed methods was tested with three difficult examples and the results showed the high degree of accuracy of these methods in solving geotechnical problems [48]. In another study, a coupled particle swarm and harmony search optimization algorithm was applied for difficult geotechnical problems by Cheng et al., (2012). They found out that due to the high degree of efficiency and robustness of the proposed method in solving a very complicated hydropower problem, this proposed method can be used in many complex geotechnical problems [49]. Bekdas et al., (2020) carried out investigations for the optimal design of cantilever soldier pile retaining walls embedded in frictional soils. They applied the harmony search algorithm to conduct parametrical analyses. Consequently, a comparison was made between the results of optimization and finite element solutions and indicated the effectiveness of the usage of optimization algorithms in soil mechanics problems. This study was published in the Applied Sciences from Multidisciplinary Digital Publishing Institute (MDPI) and it could receive seven citations during fifteen months [50].

6 Conclusions

In this paper, the application of the harmony search algorithm in geomechanical problems from 2011 to 2021 was reviewed. For this purpose, first, the application of har-monic search algorithm in all disciplines in this time period and based on the WOS platform was reviewed and evaluated. The reviews indicated that the amount of citations in articles related to this algorithm has an increasing trend. All evaluations and analyses showed the efficiency and acceptability of the harmony search algorithm among researchers in a wide range of disciplines. In the next step, a set of keywords related to the two main branches in geomechanics was defined and all documents were reviewed and evaluated on the WOS platform. The results of this review showed that the presented papers in different branches of geomechanics were innovative due to their connection with the harmony search algorithm and the documents that used this algorithm in their analysis received significant citations. While it is important to note that the contribution of these documents is small compared to other disciplines that have used harmony search algorithm. As a result, it is recommended that researchers use the harmony search algorithm as a powerful and robust tool in solving various problems in geomechanics according to the high efficiency of this algorithm, the increasing trend of citations to works related to this algorithm, and its significant contribution among the reputable publishers.

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