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Hybrid metaheuristic algorithms: a recent comprehensive review with bibliometric analysis

Ahmed M. Nassef[1,2], Mohammad Ali Abdelkareem[3], Hussein M. Maghrabie[4], Ahmad Baroutaji[5]
[1]Department of Electrical Engineering, College of Engineering in Wadi Al Dawasir, Prince Sattam bin Abdulaziz University, Wadi Al Dawasir, Saudi Arabia
[2]Computers and Automatic Control Engineering Department, Faculty of Engineering, Tanta University, Tanta, Egypt
[3]Department of Sustainable and Renewable Energy Engineering, University of Sharjah, Sharjah, United Arab Emirates
[4]Department of Mechanical Engineering, Faculty of Engineering, South Valley University, Qena, Egypt
[5]School of Engineering and Applied Science, Aston University, Birmingham, United Kingdom

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ABSTRACT

Metaheuristic algorithms are widely used in various applications. Collaborating two or more algorithms in a hybrid form has shown great improvements in terms of the algorithm's performance. This paper highlights the recently published work during the last decade from a quantitative perspective. The biometric measures include the number of publications, citations, average citations per publication, h-index, and field-weighted citation impact (FWCI) based on the data extracted from the Scopus database. Statistical measures, co-occurrence and co-authorship maps, and illustrative graphs have been implemented using software tools. According to the collected data, about 3469 articles have been published during the last decade with an increasing rate of 44.1 papers per year. Most of these articles have been published as journal articles with a percentage of 68.3%, followed by conference articles occupied 29.5%. China, India and Iran contributed the largest number of articles at 1076, 965, and 239, respectively. Parouha, Verma, and Kamel, are the top-ranked authors with 14, 10, and 9 publications, respectively. The most areas of interest are computer science, engineering and mathematics with publication percentages of 27.69%, 25.55% and 13.91%, respectively. The data presented in this paper gives the researchers a clear image of this hot topic to start new research.

Corresponding Author:

Ahmed M. Nassef
Department of Electrical Engineering, College of Engineering in Wadi Al Dawasir, Prince Sattam bin Abdulaziz University
Wadi Alddawasir, Saudi Arabia
Email: a.nasef@psau.edu.sa

1. INTRODUCTION

Optimization techniques are very crucial for most of the engineering processes. This is because obtaining the best performance for a system requires its controlling parameters to be set appropriately. Estimating the best set of values for these parameters, either by minimization or maximization algorithms, is cumbersome. Even the traditional methods for obtaining the best set of parameters might be a desperate attempt as they are probably exposed to fall into the local optima locations. Gradient descent (GD) or least squared estimation (LSE) are examples of these traditional optimization methods. Trapping into local optima can be sorted out by proposing multiple initial solutions [1], [2] and an efficient balance between the exploration and exploitation phases [3], [4]. Metaheuristic optimization algorithms (MHAs) are a class of optimization techniques that are able to handle these problems and efficiently reach the optimal solution.

Accordingly, the work in MHAs is growing rapidly. These MHAs provide several benefits that include: i) Unlike conventional optimization algorithms, MHAs start with multiple initial solutions; ii) Applying the exploration and exploitation phases which avoid trapping into local optima; and iii) Demonstrate efficacy when handling complex, constrained and high-dimensional systems.

MHAs have passed many stages from their initiation until now. Figure 1 shows a timeline of the historical developments in metaheuristic algorithms [5]. In each stage, several features and capabilities are added to the approach. Metaheuristic algorithms appear in several categories [6]. Each one has considerable advantages and disadvantages. Evolutionary algorithms represent one category that draws on natural selection and genetic mechanisms for solution generation and refinement. Another category based on swarm intelligence includes popular algorithms like particle swarm optimization (PSO) and ant colony optimization (ACO). However, metaheuristics based on local search is another class with popular algorithms such as tabu search (TS) and variable neighborhood search. Each metaheuristic category is suited to a broad collection of optimization cases. Moreover, metaheuristics can be distinguished by their approach to obtaining the optimal solution. Each one utilizes either a single-solution or a population-based strategy. Single-solution strategies begin with a randomly generated solution, which is iteratively tuned to achieve the best performance. However, population-based strategies generate multiple initial solutions, all of which are iteratively updated until the best solution is identified [5]. Single-solution methodologies include TS, simulated annealing (SA), and local and iterated local search, whereas evolutionary algorithms and swarm intelligence fall under the population-based category. Genetic algorithms (GA) [7], simulated annealing (SA) [8] and differential evolution (DE) [9] as examples of the former, and particle swarm optimization [10], firefly (FF) [11], ant colony optimization [12], artificial bee colony (ABC) [13], and bat algorithm (BA) [14] exemplifying the latter. Consequently, metaheuristic algorithms are categorized into various classes based on some criteria. The most common are the source of inspiration; the size of the population; and the mechanism of solution update [15], [16]. Figure 2 shows the popular classifications of metaheuristic algorithms. Evolutionary algorithms and swarm intelligence are the most frequently utilized categories [17].

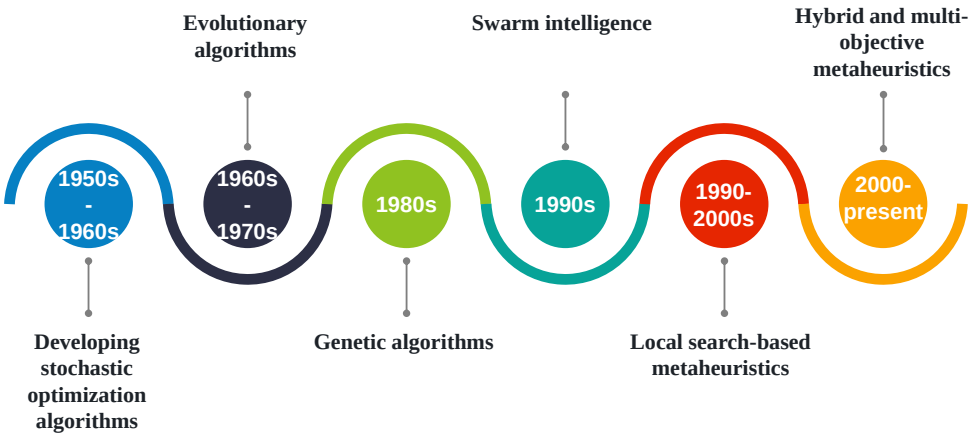

Figure 1. A timeline outlining the evolution of optimization algorithms [5]

From the no-free-lunch (NFL) theorem [18], the development of MHAs is growing rapidly [19]. This takes two approaches; either by proposing a new algorithm or modifying an existing one. Hybridization is a strategy that adopts the latter approach. Hybridization is the process of collaborating two or more algorithms to benefit from the powerful characteristics of the different algorithms [20], [21]. This strategy ends up with a hybrid optimization algorithm (HOA) [22], [23]. Despite that HOAs increase implementation complexity but improve solution quality and convergence [24], [25].

HOAs are classified into two main categories, including collaborative hybrid algorithms (CHA) and integrative hybrid algorithms (IHA) [26]. In CHA, the algorithms are running either in multi-stage, sequential or parallel and the weight of each participating algorithm can be considered equal. However, in IHA, one of the algorithms is subordinated and embedded in another main and mastering algorithm. The subordinate algorithm usually coordinates 10%-20% in the optimization process and can be applied to all or some of the entire population. It is worth mentioning that despite the HOAs providing superior performance they suffer from two main problems, including the structure complexity and the slow computational speed.

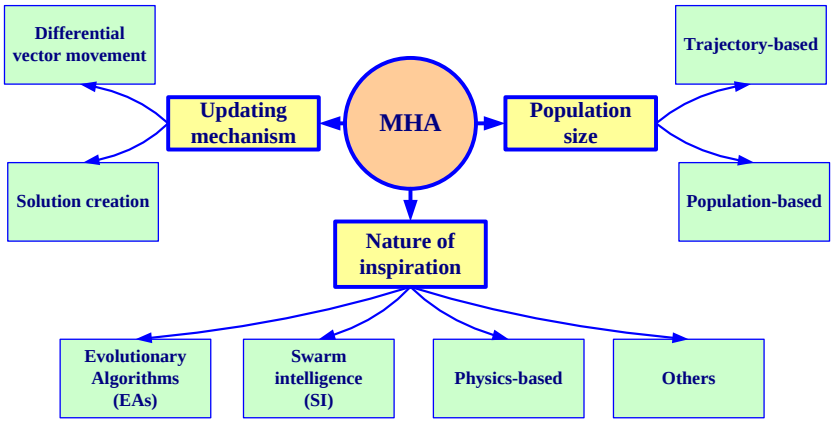

Figure 2. Common categories of MHAs [17]

In this paper, a bibliometric analysis of the work done in HOAs is produced. The analysis uses quantitative measures to provide a global overview of the topic under investigation. These measures include different markers such as the number of publications, the number of citations, and subject areas. A thorough manual that discusses this issue can be found in reference [27] is adopted in this work. The current work assesses and demonstrates the significance of hybrid optimization algorithms developed during the last decade. The search is applied to the Scopus database as one of the primary scientific resources. For statistical calculations and graphical illustrations, Microsoft Excel, VOS viewer [28], and Tableau Public [29] were used. Therefore, the research question can be stated as "*What are the bibliometric measures of the recent work done in hybrid optimization algorithms?*".

2. METHOD

To answer the research question, an extensive search is applied to the Scopus scientific database as it is one of the reputed scientific resources. To restrict the resulting articles to the addressed subject only, the search criterion is designed to consider most likely synonyms. Furthermore, the search considered only the articles written in English and the range is set to the last decade, i.e., 2013-2024. Document types such as data paper, note, editorial, letter and erratum are excluded from the search. Accordingly, the following research criterion is implemented on May 04, 2024: $TITLE$ ("$hybrid\ optimisation$" OR "$hybrid\ optimiser$" OR "$hybrid\ optimization$" OR "$hybrid\ optimizer$" OR "$Hybrid\ algorithm$" OR "$Hybrid\ algorithms$" OR "$Hybrid\ Metaheuristic$") $AND\ PUBYEAR > 2013\ AND\ PUBYEAR < 2024\ AND$ ($LIMIT-TO$ ($LANGUAGE$,"$English$")) AND ($EXCLUDE$ ($DOCTYPE$,"dp") $OR\ EXCLUDE$ ($DOCTYPE$,"no") $OR\ EXCLUDE$ ($DOCTYPE$,"ed") $OR\ EXCLUDE$ ($DOCTYPE$,"le") $OR\ EXCLUDE$ ($DOCTYPE$,"tb") $OR\ EXCLUDE$ ($DOCTYPE$,"er")).

As a result, around 3,502 documents were found matching the search criterion. In this systematic review, the preferred reporting items for systematic reviews and meta-analyses (PRISMA) [30] technique is applied. This technique is composed of three consecutive stages, including Identification, Screening, and Inclusion. In the first stage, the duplicate articles are identified and removed. Then, the irrelevant articles are screened and excluded. Finally, the final list is included in the review process. Therefore, the PRISMA methodology guides the researcher to refine the initial list of articles to reach a final list that contains the most significant articles. In this work, a final list of 3,469 articles was compiled after applying the PRISMA technique. Figure 3 shows the flowchart of the protocol used in this paper.

For implementing the bibliometric analysis, the publications list obtained from the search was saved in research information systems (RIS) and comma separated values (CSV) file formats which then formed the inputs to the VOS viewer and the Microsoft Excel, respectively. It is recommended to export the whole data of the articles such as citations, bibliographic, abstracts, keywords, funding details, and other information. All the information in this dataset was used to examine the trends of the publications such as top researchers, co-authors, affiliations, countries, and funding agencies. For calculating the publishing trends, publications' data was transferred to Microsoft Excel. Accordingly, each record in the resulting dataset was subject to either Publish or Perish. The study also included co-authorship and co-occurrence evaluations using the VOS viewer software. Visualization maps showing interconnected and linked networks were made using this software to evaluate the impact of partnerships, hotspots, and the literature's study on the HOAs topic.

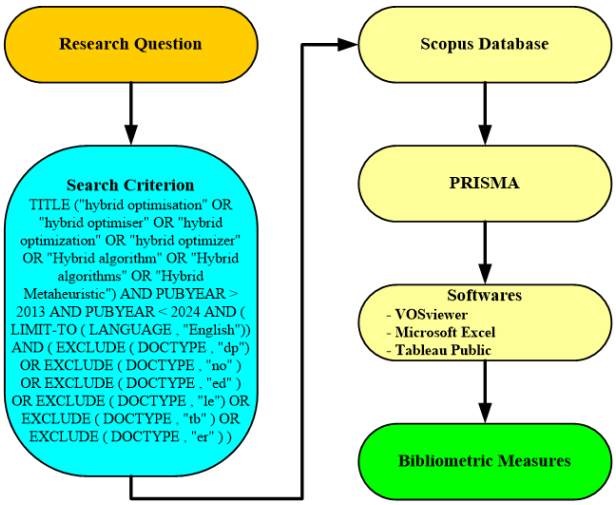

Figure 3. Flowchart of the adopted approach in this study

3. RESULTS AND DISCUSSION

All the records in the dataset are processed to produce the values of the considered markers to assess the significance of the addressed topic. Six measures are included in this study, including the publication size, publication source and document type, impact of hybrid optimization algorithms research, top countries, institutions and subject areas, top authors, and finally keywords co-occurrence analysis. The following are the details of each parameter.

3.1. Publication size

The publication size of a research topic is a considerable measure proportional to the importance of this topic. The work in hybrid MHAs shows an increase in the number of publications during the last ten years from 2014 to 2023. Figure 4 shows the distribution of the published work throughout the last decade. Around 3,469 papers, out of 9,750 articles on the MHAs topic, have been published in this period. This implies that the topic of HOA accounts for 35.58% of the entire publications in the field of metaheuristic algorithms. From Figure 4, it can be noticed that the number of publications in HOA started from 186 in 2014 and reached 627 in 2023 with an increasing rate of 44.1 papers per year. Figure 4 also illustrates that there is a continuous increase in the number of publications. The rate of this increase during the 1st five years reaches 53.76% while, it is 61.60% in the 2nd half of the decade. This indicates that this topic gained more interest from the researchers in the field. The number of publications in late 2019 has dropped due to the coronavirus disease 2019 (COVID-19) pandemic and the associated reduction in international collaborations [31]. In this period, most of the research was directed to the modeling and prediction of the pandemic to find a practical and final solution [32] and new challenges then emerged in the scientific community [33].

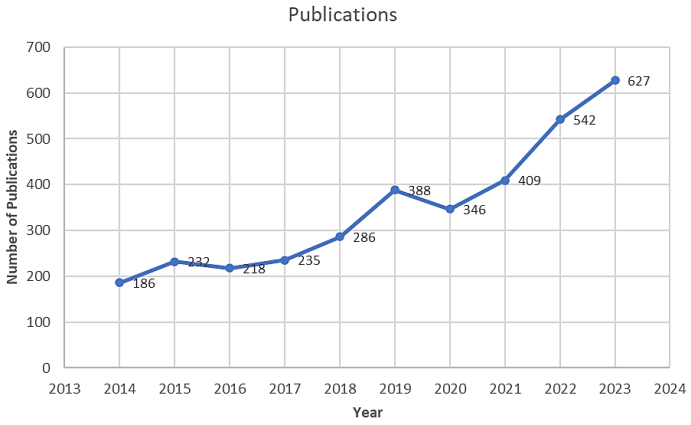

Figure 4. Publication distribution of hybrid optimization algorithms throughout the last decade

3.2. Publication source and document type

In addition to the publication size, the quality of publications is an important marker. Figure 5 illustrates the top five publication sources. These sources include lecture notes in computer science (Publisher: Springer Nature), IEEE Access (Publisher: IEEE), advances in intelligent systems and computing (Publisher: Springer Nature), expert systems with applications (Publisher: Elsevier ScienceDirect) and soft computing (Publisher: Springer Nature). The numbers of publications in each of these five sources were 59, 53, 36, 33, and 32, respectively. The first source is a book series, while the remaining four sources are from highly-ranked international journals and according to Scopus ranking they are categorized in the Q1 quartile. Figure 3 shows the yearly distribution of the published articles in the top five journals throughout the last decade. Another important indicator is document type. Most of the published papers are journal articles with a percentage of 68.3% followed by conference papers with a percentage of 29.5%, yielding an overall percentage of 97.8% of the entire publications in the addressed topic. Figure 6 illustrates the types of published articles in HOA during the last decade.

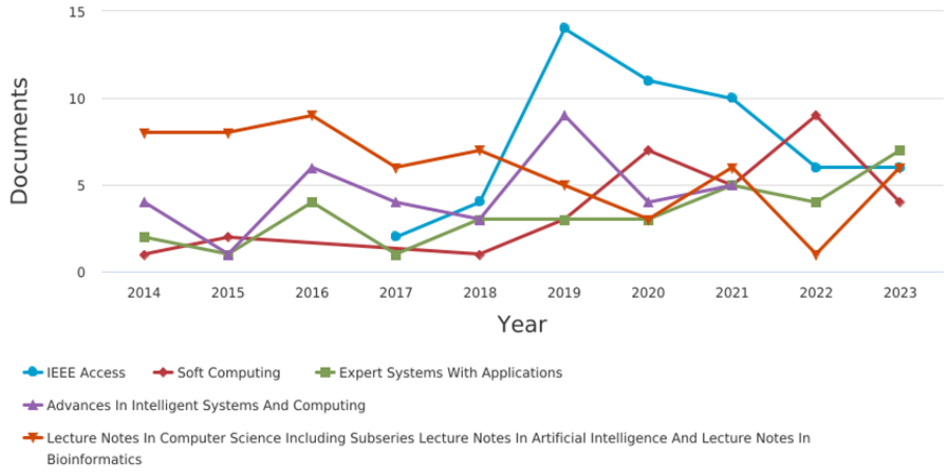

Figure 5. Publication sources of hybrid optimization algorithms during the last decade

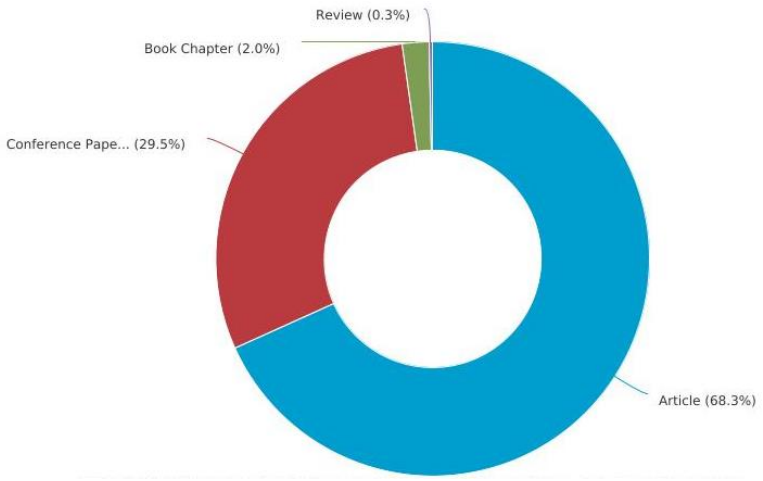

Figure 6. Types of articles published in hybrid optimization algorithms during the last decade

3.3. Impact of hybrid optimization algorithms research

The total citations of HOA publications were 36,983 during the last 10 years. In 2014 the citations were at 2,721 and became 1,394 in 2023. The 5-year averages of the 1st and 2nd halves of the decade are 3,704 and 3,692.6, respectively. These values imply that there was an increasing number of citations over the value of 2014. Also, the overall average of total citations is 3,698.3 which is still above the starting value

found in 2014. The yearly citations and their averages are illustrated in Figure 7. Furthermore, Table 1 shows the most-cited publications on the HOA topic. The table does not show only the reference records such as the authors, year of publication, the journal (source), number of citations and their percentage but also adds remarkable data such as field-weighted citation impact (FWCI) and the composition of the new hybrid algorithm. FWCI is adopted by Scopus and can be considered a quality measure. Particularly, FWCI shows how well the document citation is when compared to similar documents. For a document having an FWCI value greater than 1.00, it indicates that this document is cited more than the average. According to Scopus, the FWCI is an accumulative measure as it is calculated from the ratio of the document's citations to the average number of citations received by all similar documents over a three-year window. By doing this, each discipline will have an equal contribution to the metric which helps to eliminate the differences in researcher citation impact.

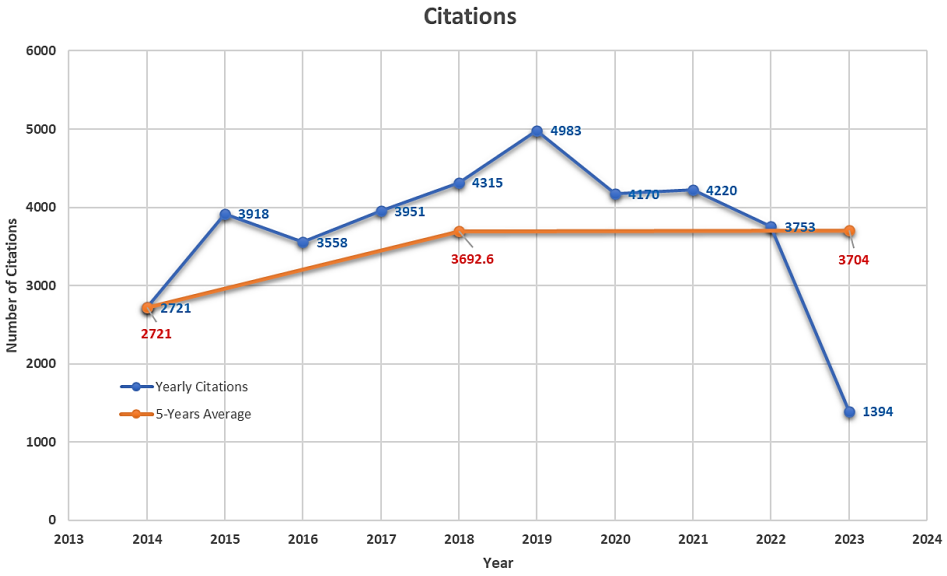

Figure 7. Citations distribution of hybrid optimization algorithms during the last decade

Based on the FWCI metric, all the references illustrated in Table 1 have FWCI values above 1.0 which indicates their high qualities. Also, four references (written in bold in Table 1) out of ten have values of more than 10.0 which demonstrates their outstanding rank among the other work in the field. The work in these references has been done by Long *et al.* [34], Arora *et al.* [35], Shunmugapriya and Kanmani [36] and Khalilpourazari and Khalilpourazary [37]. From Table 1, it can be noticed that grey wolf optimizer (GWO) occupies the first rank among the other optimizers as it participated in the production of 4 new algorithms out of 10. The PSO and GA came in the second rank each as they participated in generating 2 new optimizers out of 10.

Table 1. The recent most-cited publications in HOA and their FWCI values

	Author	Composition of the hybrid algorithm	Year	Publication Source	Citations	%	FWCI
1	Awasthi *et al.* [38]	GA and PSO	2017	Energy	253	0.68%	7.13
2	Long *et al.* [34]	GWO and CS	2020	Energy Conversion and Management	240	0.65%	14.3
3	Sahebjamnia *et al.* [39]	GA, SA, TS, RDA, WWO	2018	Journal of Cleaner Production	218	0.59%	8.05
4	Singh and Singh [40]	GWO and PSO	2017	Journal of Applied Mathematics	208	0.56%	6.51
5	Arora *et al.* [35]	GWO and CSA	2019	IEEE Access	185	0.50%	12.81
6	Shunmugapriya and Kanmani [36]	ACO and ABC	2017	Swarm and Evolutionary Computation	185	0.50%	14.8
7	Khalilpourazari and Khalilpourazary [37]	WCA and MFO	2019	Soft Computing	169	0.46%	15.07
8	Qiao *et al.* [41]	LSO and GA	2020	Journal of Cleaner Production	166	0.45%	8.14
9	Yu *et al.* [42]	WCO and FSO	2019	Energy Reports	153	0.41%	6.19
10	Zhang *et al.* [43]	BBO and GWO	2018	Applied Soft Computing Journal	141	0.38%	5.88

3.4. Countries, institutions, and subject areas

In the work on HOA, some countries and institutions showed more interest than others. This can be concluded from the number of publications affiliated with some countries or institutions. Referring to the resulting data, China, India, and Iran acquired more than half of the publications. However, the top-10 countries list contains China, India, Iran, the USA, Turkey, Saudi Arabia, France, the United Kingdom, Malaysia and Egypt. These countries contributed with the largest number of articles at 1,076 (24.45%), 965 (21.93%), 239 (5.43%), 195 (4.45%), 114 (2.59%), 92 (2.09%), 82 (1.86%), 79 (1.80%), 78 (1.77%) and 76 (1.73%), respectively. Figure 8 shows the country-wise distribution of the work done in hybrid MHA distributed on the world map. In the same context, the Ministry of Education of China, the Chinese Academy of Sciences, and the Vellore Institute of Technology in India are the most contributed institutions with 69, 39, and 32 articles, respectively. The top-5 subject areas according to the resulting publications are found computer science, engineering, mathematics, physics and energy with publications of 2008 (27.69%), 1853(25.55%), 1009 (13.91%), 377 (5.20%), and 359 (4.95%), respectively. These figures clearly show that the two areas of Computer Science and Engineering acquire more than half of the publications.

Figure 9 illustrates the top-20 institutions while the top-5 subject areas published in HOAs are shown in Figure 10. Because of their competitive accuracies and performances, hybrid algorithms are utilized in many engineering applications [44] such as feature selection [45]–[47], automatic speed control systems [48], rules mining [49], optimal load shedding strategy [50], neural network training [51], electrical load, and price forecasting [52].

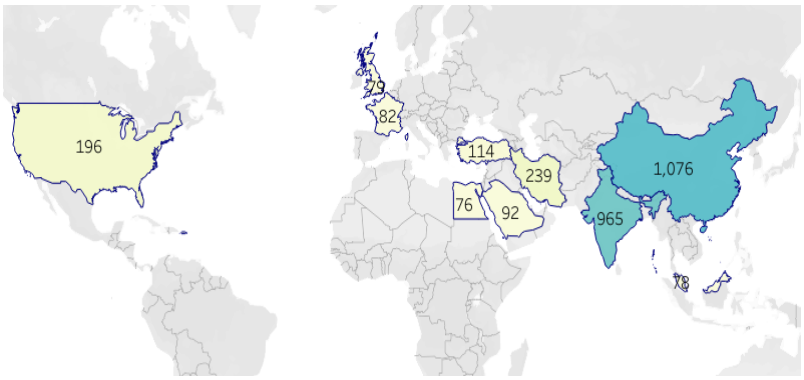

Figure 8. A map of top-10 country-wise distribution of hybrid MHA publications

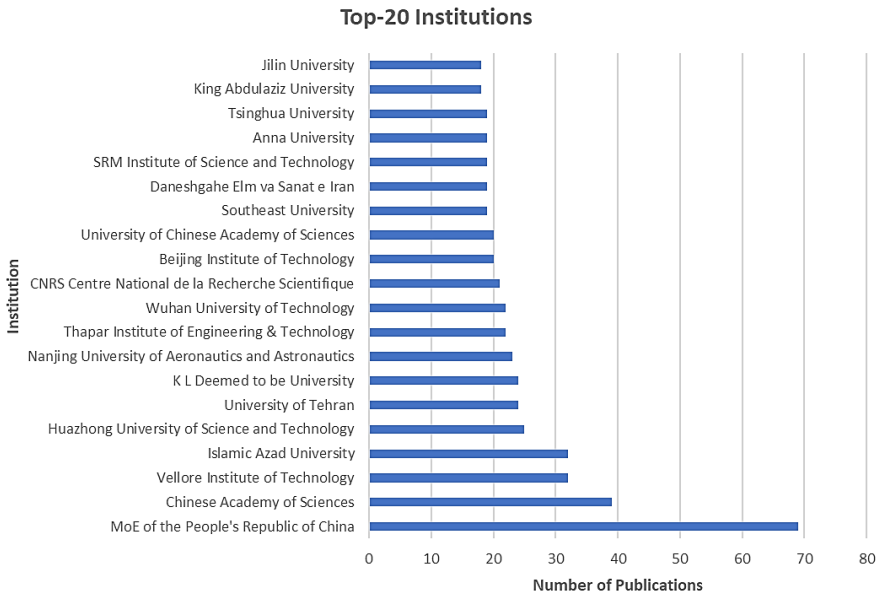

Figure 9. Top-20 institutions published in hybrid optimization algorithms

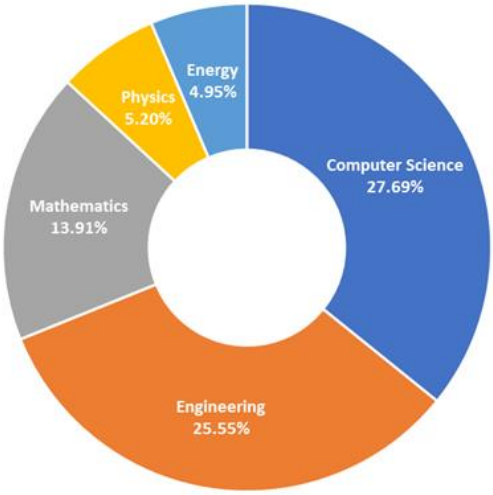

Figure 10. Top-5 subject areas published in hybrid optimization algorithms

3.5. Top authors

As expected, the list of top ten authors who have published many papers on HOA includes authors from China and India. Table 2 provides the important data of the top-ten authors. It can be seen from the table that four authors are from China and three authors are from India. The remaining authors are from Egypt, Belgium, and Thailand. To avoid confusion with a similar author's name, Scopus ID is added to the author's data as shown in Table 2. Also, the work in HOAs has more interest from the first two authors Parouha and Verma as it represents most of their work. According to Scopus, most of the contributions of the two authors are in evolutionary algorithms, differential evolution algorithms and benchmarking. The paper of Parouha published in 2021 [53] has 12 citations (FWCI=2.68). In their work, a combination of DE and PSO has been done to produce a new hybrid optimizer namely, DE-PSO-DE (DPD). The new hybrid optimizer is applied to solve the economic load dispatch (ELD) problem. With the DE and PSO, Verma and Parouha have also published a recent work with 4 citations (FWCI=1.94) [54]. The authors from China; Chu, Gao, Li, and Pan have relatively high h-index and FWCI with values of 41, 84, and 63 (FWCI=1.80, 2.43 and, 2.69), respectively. Pan and Chu developed a hybrid optimizer based on the teaching-learning-based optimization (TLBO) and DE and tested their work on test suite CEC 2017 [55]. This work is cited 91 times and its FWCI is 7.30, indicating the high quality of the work. However, the work done in 2016 by Xinyu Li introduces the use of GA and TS to generate a hybrid algorithm to solve flexible job shop scheduling problem (FJSP) [56]. It is found that the paper is cited 426 times with an FWCI value of 23.39. The top ten authors published in HOA during the last decade are plotted in Figure 11.

Table 2. The data of the top ten authors worked in the hybrid optimization algorithms

	Name	Scopus ID	Published papers	Papers in HOA	Affiliation	h-index	FWCI
1	Parouha, Raghav Prasad	56136342500	40	14	Indira Gandhi National Tribal University, Amarkantak, India	11	0.79
2	Verma, Pooja	57211908560	14	10	Indira Gandhi National Tribal University, Amarkantak, India	6	0.70
3	Chu, Shu Chuan	7403622006	366	9	Shandong University of Science and Technology, Qingdao, China	41	1.80
4	Gao, Liang	56406738100	1039	8	Huazhong University of Science and Technology, Wuhan, China	84	2.43
5	Kamel, Salah	36782335000	896	8	Aswan University, Aswan, Egypt	53	2.06
6	Li, Xinyu	56021323400	409	8	Huazhong University of Science and Technology, Wuhan, China	63	2.69
7	Agostoni, Pierfrancesco	57226223987	359	7	ZiekenhuisNetwerk Antwerpen, Verviers, Belgium	54	1.40
8	Bhattacharyya, Biplab	12764731800	107	7	Indian Institute of Technology (Indian School of Mines), Dhanbad, Dhanbad, India	25	1.70
9	Pan, Jeng Shyang	57214682289	1098	7	Shandong University of Science and Technology, Qingdao, China	63	1.33
10	Suantai, Suthep	55891592800	264	7	Chiang Mai University, Chaing Mai, Thailand	27	1.07

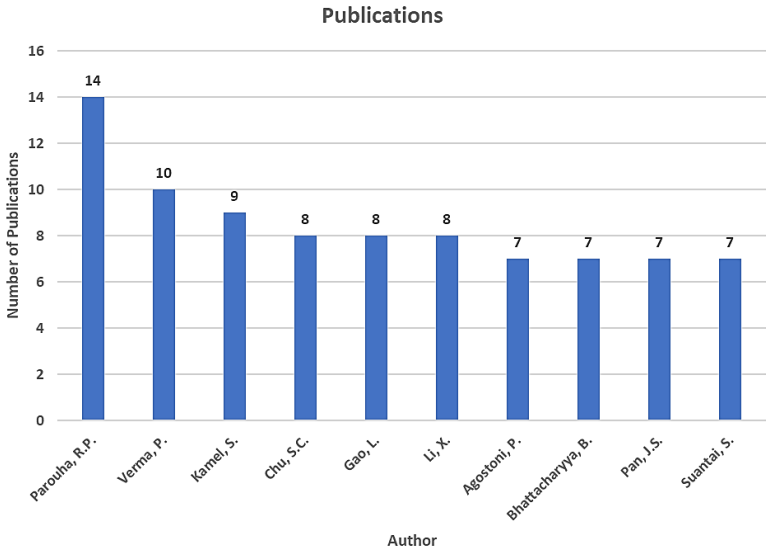

Figure 11. Top-10 authors published in hybrid optimization algorithms during the last decade

The study is extended to the analysis of the co-authorship network. Accordingly, VOSviewer software was used to implement this job. The co-authorship network is a visual illustration tool to show the collaboration strengths between authors in the same field. The network is generated based on the data saved in an RIS file format. To create a map, use the following steps: $File > Create > Create\ a\ map\ based\ on\ bibliographic\ data > Read\ data\ from\ reference\ manager\ files$.

The database in the RIS file includes 8,412 authors. The network is generated according to the following specifications: The maximum number of authors per document is 25; The minimum number of documents of an author is 5. After applying the above specifications, a list of 241 authors is produced. Figure 9 shows the resulting co-authorship map with the networking links. It is clear from the figure, most of the authors are from China. Each author is denoted by a bubble as shown in Figure 12. However, the size of this bubble is proportional to the number of published papers by the associated author. By analyzing the co-authorship map, it is noticed that the work in hybrid optimization algorithms contains 14 clusters. Each cluster is denoted by a specific color to be discriminated from the others. Also, the link size between any two co-authors determines the strength between them.

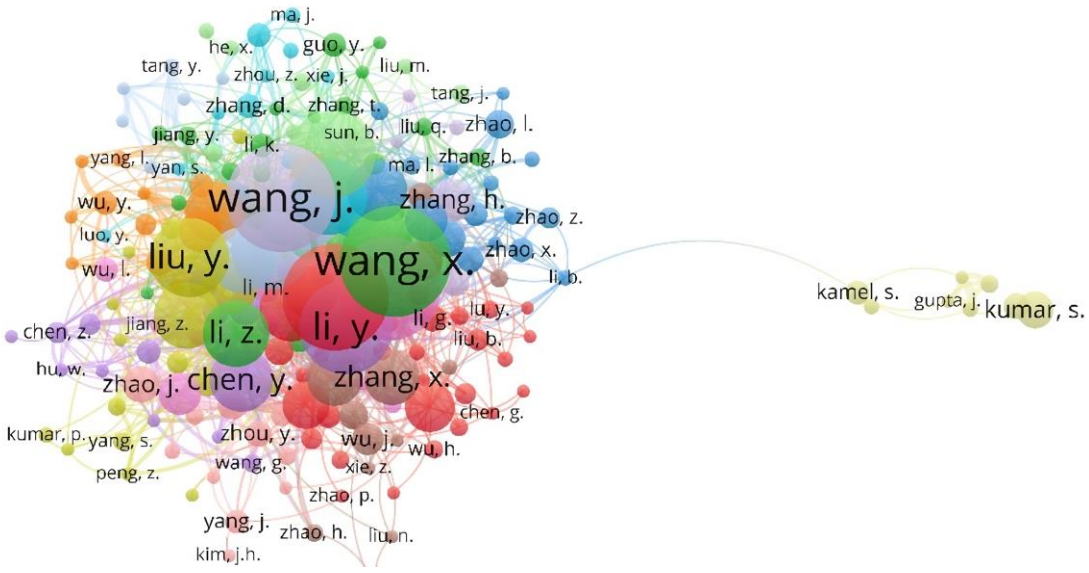

Figure 12. Co-authorship map of the top authors worked in hybrid optimization

3.6. Keywords co-occurrence analysis

The analysis of the keyword co-occurrence has been done using the VOSviewer software. The steps are similar to generating the 'co-authorship' map but select 'co-occurrence' instead. In this map, the minimum number of occurrences of a keyword is set to 50. From a total of 21,661 keywords, 85 keywords meet the threshold. Figure 13 shows the resulting map of the co-occurring keywords and their interconnected network related to the hybrid optimization algorithms. The 85 keywords are classified into 4 clusters. Based on their occurrence, the five most common keywords are optimization, hybrid algorithms, particle swarm optimization, genetic algorithms and hybrid optimization algorithms have occurrences of 828, 960, 559, 591, and 300, respectively. It can be noticed from Figure 13 that hybrid algorithms have been used in many fields and applications. These applications include energy utilization, classification of information, scheduling, image segmentation, vehicle routing, data mining, parameter estimation, and stochastic systems.

In summary, Table 3 provides the Top-10 in all the metrics mentioned in this paper. The table lists the top ten countries, authors, subject areas, sources and affiliations that worked on the topic of hybrid optimization algorithms. Therefore, this table can be a reference for any researcher interested in this topic.

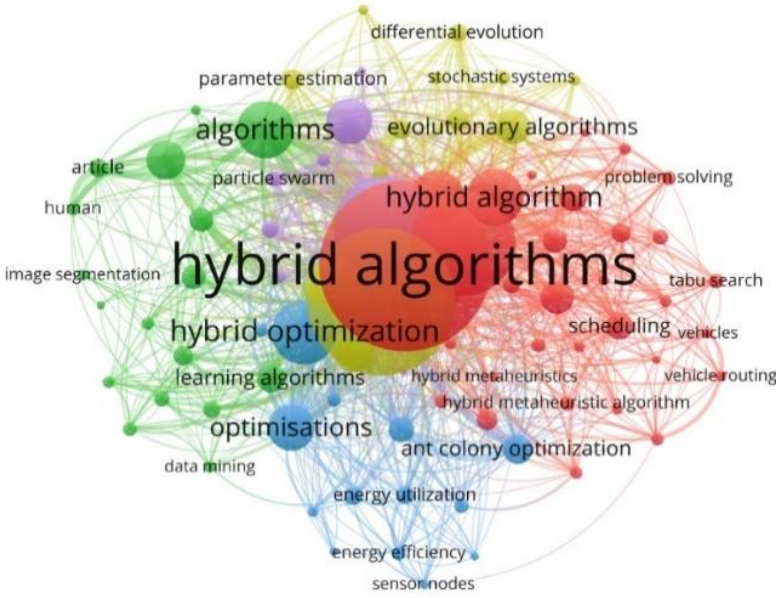

Figure 13. Co-occurrence map of hybrid optimization algorithms and the related keywords

Table 3. Summary of the work in the hybrid optimization algorithms

No.	Country	Author	Subject Area	Source Title	Affiliation
1	China	Parouha, Raghav Prasad (India)	Computer Science	Lecture Notes In Computer Science	Ministry of Education of the People's Republic of China
2	India	Verma, Pooja (India)	Engineering	IEEE Access	Chinese Academy of Sciences
3	Iran	Chu, Shu Chuan (China)	Mathematics	Advances In Intelligent Systems and Computing	Vellore Institute of Technology
4	United States	Gao, Liang (China)	Physics	Expert Systems With Applications	Islamic Azad University
5	Turkey	Kamel, Salah (Egypt)	Energy	Soft Computing	Huazhong University of Science and Technology
6	Saudi Arabia	Li, Xinyu (China)	Materials Science	Journal of Physics Conference Series	University of Tehran
7	France	Agostoni, Pierfrancesco (Belgium)	Decision Sciences	Energies	K L Deemed to be University
8	United Kingdom	Bhattacharyya, Biplab (India)	Environmental Science	Mathematical Problems in Engineering	Nanjing University of Aeronautics and Astronautics
9	Malaysia	Pan, Jeng Shyang (China)	Business, Management and Accounting	Lecture Notes in Networks and Systems	Thapar Institute of Engineering & Technology
10	Egypt	Suantai, Suthep (Thailand)	Social Sciences	Applied Soft Computing Journal	Wuhan University of Technology

4. CONCLUSION AND FUTURE WORK

Metaheuristic algorithms have shown a significant role in the optimization field. To make a system operate at its best performance state, metaheuristic algorithms can be utilized to produce the best set of controlling parameters. Hybridization of two or more algorithms proved the production of an algorithm with superior performance than the original algorithms when used individually. In this paper, a recent comprehensive review along with a bibliometric analysis of the hybrid metaheuristic algorithms has been presented. The study focuses only on the recent research papers published during the last decade (2014-2023). The work starts by stating the research question as "What are the bibliometric measures of the recent work done in hybrid optimization algorithms?". Based on the research question, an extensive search process has been done within the Scopus database. The research question is translated into a search criterion which has been designed to consider all the possible synonyms and keywords. The search process was executed on May 04, 2024, and produced an initial set of 3,502 articles. Using PRISMA methodology, the duplicate and irrelevant articles have been excluded and the final list was 3,469 papers. The resulting set of articles was subjected to further processes to extract the appropriate biometric measures. These measures included the number of publications, citations, average citations per publication, h-index and FWCI. Furthermore, statistical measures, co-occurrence and co-authorship maps and illustrative graphs have been produced using Microsoft Excel, VOSviewer and Tableau Public software programs. The results showed there is an increase in the HOA publications by a rate of 44.1 papers per year. Most of these articles are journal articles with a percentage of 68.3% of the total publications. Furthermore, the articles were published in highly-ranked journals such as IEEE Access and Advances in Intelligent Systems and Computing. It is noticed that the authors from China, India, and Iran contributed the largest number of articles at 1076, 965 and 239, respectively. Accordingly, the institutions as well as the authors from these nations have advanced positions over the others regarding the publication in HOA. Parouha, Verma, and Kamel, are the top-ranked authors with 14, 10, and 9 publications, respectively. The HOAs are utilized in many fields and it is found that the areas of interest are computer science, engineering and mathematics. The publications in these subject areas have percentages of 27.69%, 25.55%, and 13.91%, respectively. The top-10 countries, authors, subject areas, sources and affiliations are summarized in a single table. In conclusion, the data presented in this paper can give the researchers in the field a clear and thorough image of the work done on this hot topic to be used as a starting guide. Accordingly, and from the NFL principle, researchers can find this data useful to initiate new research points. In the future, another class of MHA can be considered for further investigations.

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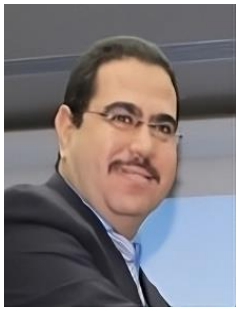
BIOGRAPHIES OF AUTHORS



Ahmed M. Nassef received his B.Sc. degree (with honors) from the Computers and Automatic Control Engineering Department, Faculty of Engineering, Tanta University, Egypt, in 1995. Then, he got the M.Sc. degree in automatic control and systems engineering from Mansoura University, Mansoura, Egypt, in 2000 and the PhD degree from the Department of Automatic Control and Systems Engineering, Faculty of Engineering, University of Sheffield, Sheffield, U.K., in 2009. He is permanently working as an associate professor and a teacher of fuzzy systems and artificial neural networks in the Faculty of Engineering, Tanta University, Tanta, Egypt. Currently, Dr. Nassef is working as an associate professor in the Electrical Engineering Department, College of Engineering at Wadi Al-Dawasir, Prince Sattam Bin Abdulaziz University, KSA. His research interests include intelligent systems and their applications to biomedical and industrial engineering, fuzzy systems, neural networks, metaheuristic algorithms, optimization, and renewable energy. He can be contacted at email: a.nasef@psau.edu.sa.

Mohammad Ali Abdelkareem spent 7 years in one of the pioneer labs in Japan in the field of electrochemical energy devices, i.e., fuel cells. During his PhD study, Dr Mohammad developed a novel electrode structure for direct methanol fuel cell (DMFC), thereby; the methanol concentration which can be used efficiently in DMFC has been increased from 7 to 100 weight%. Dr Mohammad enrolled in various postdoctoral fellowships in Japan for the development of the electrodes of the direct methanol fuel cells. Dr Mohammad back to Egypt at the end of 2012, where he secured international and national funds through them, he built up two pioneer labs in the field of the solid oxide fuel cells and microbial fuel cells. Right now, he is professor in Sustainable and Renewable Energy Engineering Department, University of Sharjah, UAE. He is working on the development of the different renewable energy resources, thermos-fluids, and electrochemical devices that can be used in wastewater treatment and water desalination. Professor Mohammad has secured several national and international research funds with more than 800,000 USD for the development of the various electrochemical energy conversion storage devices. Professor Mohammad published more than 200 manuscripts in ISI indexed journals. He can be contacted at email: mabdulkareem@sharjah.ac.ae.

Hussein M. Maghrabie graduated in 1999 from the Mechanical Engineering Department, Faculty of Engineering, Minia University, Egypt. He was employed as an assistant lecturer in the Mechanical Engineering Department (Power and Energy Section) at the same university since 1999. He received his M.Sc. in 2004 in the field of mechanical power and energy from Minia University. He joined as a Ph.D. student, at Moscow State University of Applied Biotechnology, Moscow, Russia, in 2008 and got his Ph.D. in 2011 in enhancement of freezing process in the vacuum drying technology of food products using low-temperature air from the turbo air refrigeration equipment. He worked as an assistant professor in the Mechanical Power Engineering and Energy Department, Faculty of Engineering, Minia University. Currently, he is an associate professor in the Mechanical Engineering Department, Faculty of Engineering, South Valley University, Qena, Egypt. His research interests include waste heat recovery systems; electric vehicles; heat sink and electronic components; water desalination systems; application of nanofluids; carbon capture; energy conversion and energy resources; solar energy, photovoltaics, jet impingement, and heat exchangers. He can be contacted at email: Hussein_mag@eng.svu.edu.eg.

Ahmad Baroutaji is a senior lecturer in the School of Engineering and Technology at Aston University (AU) in the UK. His academic qualifications include BSc in mechanical engineering, PhD in mechanical engineering, and PgCert in teaching in higher education. Ahmad is a Senior Fellow of the Higher Education Academy (SFHEA) and a Member of the Institution of Engineering and Technology (MIET) in the UK. Ahmad is an active researcher in the area of engineering design and additive manufacturing. His research activities contributed significantly to the fields of crashworthiness, additive manufacturing using laser powder bed fusion, metamaterials, multi-objective optimization, and hydrogen technologies. Ahmad's current research focuses on sustainable design and additive manufacturing of advanced functional materials with unprecedented mechanical performance for net-zero technologies, biomedical implants, and energy absorption applications. Ahmad has a track record of more than 60 high-quality peer-reviewed journal papers and 40 book chapters in leading scientific journals and book series. He received internal and external funding for his research, supervised Ph.D. students to completion, and supervised post-graduate apprenticeship students to carry out impactful industrial projects. He can be contacted at email: a.baroutaji@aston.ac.uk.