Bibliometric Analysis of Particle Swarm Optimization (PSO) Research 2000-2010

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***Abstract*—In the last decade, Particle Swarm Optimization (PSO) has grown in popularity as one important method for optimization, compared to recent Differential Evolution (DE) and Harmony Search (HS). In this paper a bibliometric study is presented, carried out on the PSO research literature from 2000 to 2010. The Thomson Reuters Web of Science (WoS) was used to collect publication records and analyzed to identify authorship, co-authorship, top journals, profile the distribution of citations and references. The study also include the use keyword co-occurrence frequency from the articles' title, to help getting insights into PSO research trends and fields of applications.**

***Keywords*-Particle Swarm Optimization; bibliometric study; citations;**

I. INTRODUCTION

Since its introduction in 1995 by J. Kennedy and R. Eberhart [1], Particle Swarm Optimization (PSO) has enjoyed a large popularity compared to other recent methods, from the pioneering Genetic Algorithm (GA) [2], such as as Differential Evolution (DE) [3] or Harmony Search (HS) [4].

The aim of this study was to create an accurate bibliometric picture of the current state of PSO research from its research literature, identifying the most eminent researchers, their collaborations, their country of origin, citation and reference distribution patterns, and finally study keywords related to this research field to get insights into applications, hot topics and trends in PSO research.

The remainder of the paper is organized as follows. In Section II we detail the analysis procedure. In Section III we present the results from the bibliometric study. Finally in Section IV, we conclude the paper.

II. METHODOLOGY

The Web of Science (WoS) online interface (Thomson Reuters) was used to retrieve records (with full abstract and references) of articles on PSO. For each year, one file with all the entries is saved in text format. The records are subsequently processed using MATLAB scripts. The query, use for the year 2009 for e.g., was of the form *Topic=(particle* swarm optimization) AND Year Published=(2009) AND Language=(English) Timespan=All Years. Databases=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH.*. The procedure is similar as the one used in previous bibliometric studies [5][6].

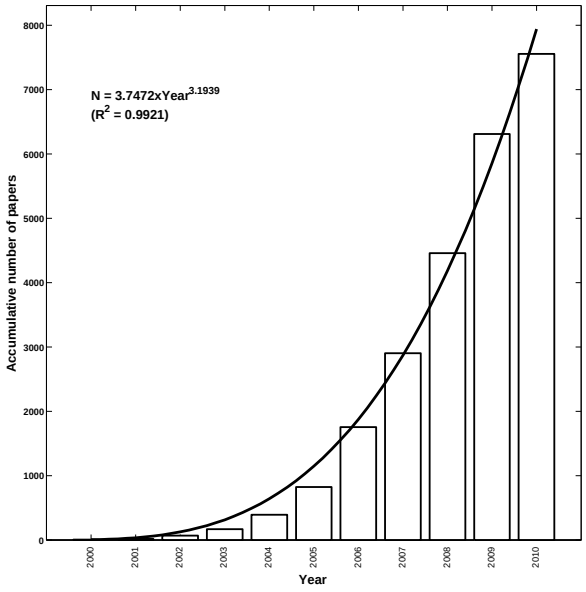

Figure 1. Growth of the PSO research literature from 2000 to 2010

III. RESULTS

A. Growth

The growth of the PSO research literature from 2000 to 2010 is shown in Figure 1. Its characteristic was fitted with a power-law curve with the following $N = a \times x^b$, with $a = 3.7472$ and $b = 3.1939$ ($R^2 = 0.9921$).

B. Authorship

As shown in Figure 2 the majority co-authors is around 1 to 5, with a peak at 2 to 3. In Figure 3, a more detailed picture is shown with the number of co-authors versus number of papers on a yearly basis. We can see an increasing number of papers in the recent years (e.g. in 2010 shown using $\star$). The most eminent researchers are listed in Table I, ranked using harmonic counting [7] which provides a more objective measure than the number of publications or geometric counting, to avoid potential bias [8].

C. Citations

A loglog scatter plot shows the number of papers versus the number of citations in Figure 4. It has a typical fat tail characteristic. This distribution is robustly fitted with

Table I
PSO RESEARCHERS RANKED BY HARMONIC COUNTING

Rank	Name	NP	Harmonic	Arithmetic
1	LIU, Y	147	53.259	92.726
2	WANG, Y	169	52.458	98.267
3	WANG, J	142	51.732	90.193
4	WANG, X	136	46.602	84.883
5	CHEN, Y	122	46.129	80.433
6	WANG, L	136	45.229	81.767
7	LI, Y	125	41.215	75.317
8	ZHANG, X	119	41.157	83.417
9	LI, X	106	38.595	66.302
10	ZHANG, Y	128	38.512	71.483
11	ZHANG, J	117	34.393	62.535
12	SUN, J	102	32.305	61.144
13	LIU, H	82	31.720	52.883
14	VENAYAGAMOORTHY, G	100	31.686	51.533
15	COELHO, L	52	29.807	42.750
16	LIU, J	84	28.449	52.433
17	XU, W	105	27.142	48.410
18	LI, L	79	25.871	48.967
19	LI, J	75	24.693	43.200
20	LIU, X	70	24.558	45.167
21	WANG, H	74	22.768	43.367
22	WANG, D	72	22.377	41.150
23	ZHANG, H	59	22.258	38.774
24	ZHANG, W	60	21.884	37.583
25	LIU, W	54	21.790	39.783
26	CHEN, J	68	21.558	39.500
27	LI, Z	59	20.533	37.117
28	WU, Q	63	20.351	30.650
29	CHEN, C	54	20.118	34.792
30	LIN, C	49	19.659	33.867
31	ZHANG, L	62	19.276	37.783
32	CUI, Z	41	18.417	31.833
33	YANG, S	59	18.181	33.950
34	ZHANG, C	56	17.737	33.050
35	ZHANG, Q	51	17.683	30.626
36	ZENG, J	67	17.555	31.917
37	LI, M	47	17.170	31.200
38	ABRAHAM, A	79	17.002	32.383
39	HUANG, Y	48	16.953	31.417
40	CHEN, H	48	16.660	30.700
41	WANG, Z	53	16.451	31.144
42	WANG, C	60	16.377	29.467
43	WU, J	45	16.249	30.076
44	WANG, S	55	16.174	30.400
45	GAO, Y	35	16.023	28.083
46	LI, C	49	15.887	27.983
47	CHEN, W	49	15.779	29.361
48	WANG, W	56	15.649	29.650
49	YANG, C	56	15.541	29.667
50	LI, W	56	15.149	29.883

NP: number of publications

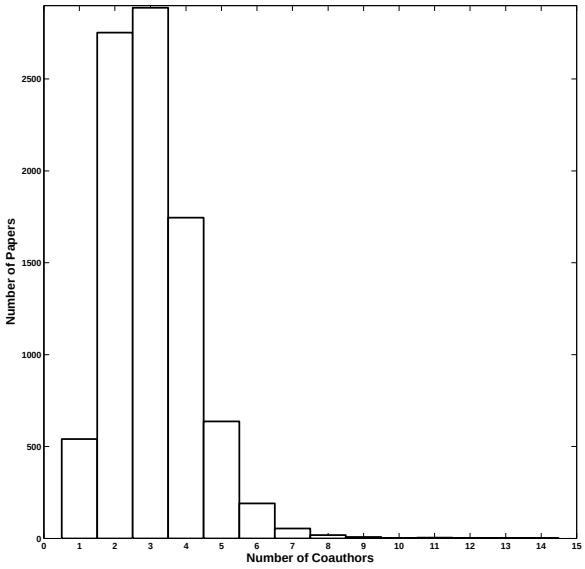

Figure 2. Authorship distributions of the PSO articles

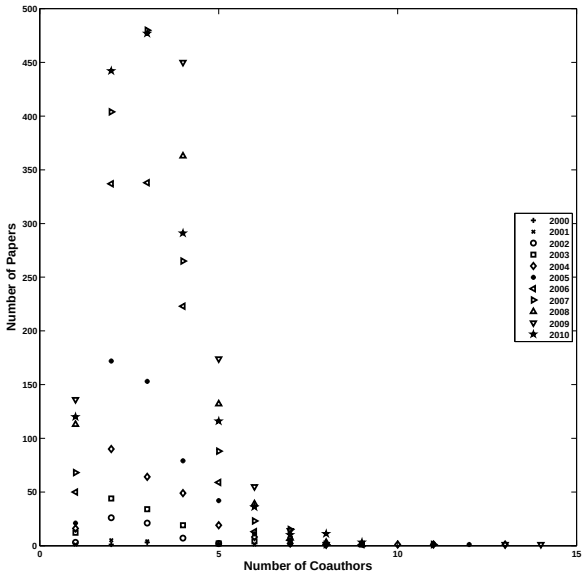

Figure 3. Yearly authorship distribution of the PSO articles

a power-law curve (shown as a line due to the loglog scale axis).

The paper with the highest number of citations was by M. Clerc about *The particle swarm - explosion, stability, and convergence in a multidimensional complex space* [9], with 1191 citations.

D. References

Citation counts are related to the number references citing other articles, thus it is important to assess such aspect over the years. The distribution of the number of references is shown in Figure 5. From 2000 to 2010, the yearly average number of references per article grew from 18.33 to 31.47 (median 19.77 to 26.05). Articles with large number of references are often reviews like the one on *an exploration of the literature on the use of 'swarm intelligence-based techniques' for public service problems* [10](with 165 references) or the *survey on algorithms simulating bee swarm intelligence* [11](with 161 references).

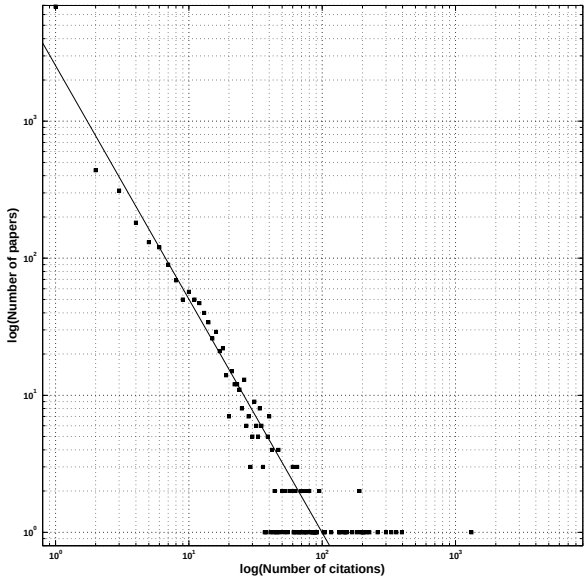

Figure 4. Citations distribution for the PSO literature

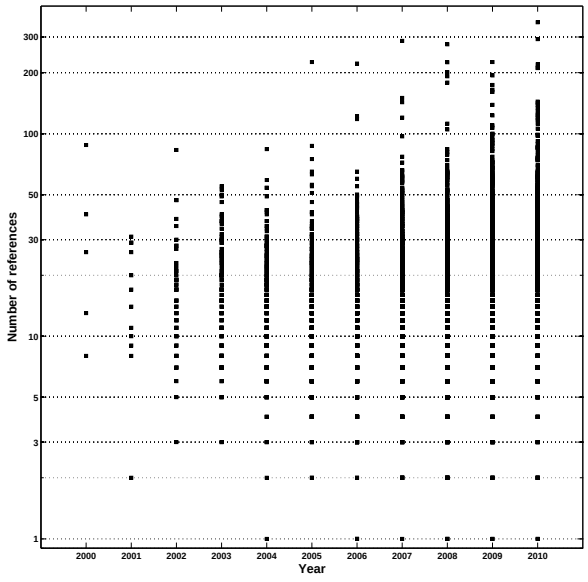

Figure 5. Distribution of the references in PSO articles

E. Country of origin

There are in total 65 countries contributing to the PSO literature and include China (632, 25.92%), Taiwan (267, 10.95%), India (239, 9.80%), USA (224, 9.19%), Iran (182, 7.47%), Turkey (74, 3.04%), Japan (71, 2.91%), Brazil (63, 2.58%), Italy (55, 2.26%), U.K. (54, 2.21%), Greece (49, 2.01%), Korea (48, 1.97%), Spain (45, 1.85%), Canada (36, 1.48%), Egypt (32, 1.31%), Singapore (26, 1.07%), South Africa (26), Malaysia (25, 1.03%), Australia (23, 0.94%), Thailand (22, 0.90%), Germany (19, 0.78%), France (17, 0.70%), etc. As shown in Figure 6, China is the most

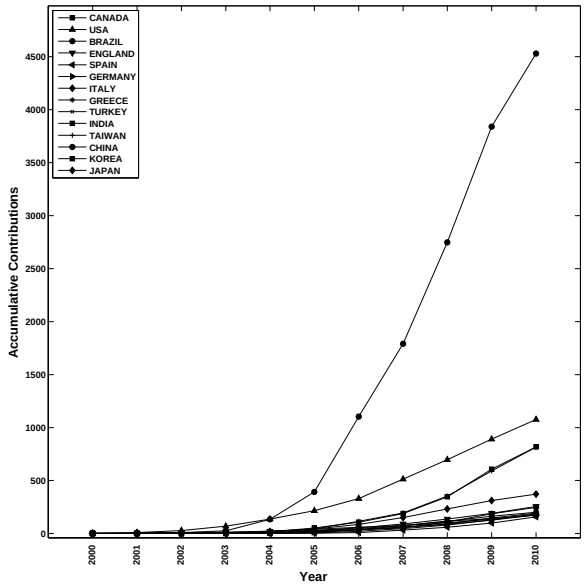

Figure 6. Countries of origin of the PSO articles' researchers

publishing country, followed by a group with Taiwan, USA and India.

F. International Collaborations

Affiliation fields of the PSO researchers were used to extract the country's international collaboration. The results are summarized in a form of a network graph as shown in Figure 7. We can observe that the majority of international collaborations occur between China and USA, and UK with China. In Figure 8, the international collaboration is shown at researchers' level (100 top researchers publishing in PSO)(See PSO researchers ranking in the *Supplementary Data* at www.tech.plymouth.ac.uk/spmc/brahim/Biblio-PSO).

G. Journals

A list all top 40 core journals publishing research in PSO is given in Table II. The list includes a broad scope of journal disciplines with computing, mathematics, and engineering (optics, energy, etc.). The journals with the highest Impact Factor (IF) [13][14] include *IEEE Transactions on Industrial Electronics* (IF: 4.678), followed by *IEEE Transactions on Evolutionary Computation* (IF: 4.589), *Progress In Electromagnetics Research (PIER)* (IF: 3.763), followed by *Chaos Solitons and Fractals* (IF: 3.315), *Information Sciences* (IF: 3.291) and *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics* (IF: 3.007).

H. Keywords

We use the tool WORDLE [12] to create TagClouds from the keywords extracted from the articles' titles. In Figure 9, the most recent years are shown. A close look at

Table II
PSO CORE JOURNALS

Rank	Name of the journal	NP	%	IF	EF	PF	Publisher
1	Expert Systems with Applications	137	1.55%	**2.908**	0.00987	12	Elsevier
2	Dynamics of continuous discrete and impulsive systems-series	93	1.05%	–	–	–	DCDIS
3	IEEE CEC 2008	92	1.04%	–	–	–	IEEE
4	IEEE CEC 2007	80	0.90%	–	–	–	IEEE
5	IEEE WCICA 2006	76	0.86%	–	–	–	IEEE
6	IEEE CEC 2010	75	0.85%	–	–	–	IEEE
7	IEEE WCICA 2008	71	0.80%	–	–	–	IEEE
8	IEEE CEC 2008	64	0.72%	–	–	–	IEEE
9	IEEE ICNC 2007	61	0.69%	–	–	–	IEEE
10	IEEE NaBIC 2009	58	0.66%	–	–	–	IEEE
11	IEEE Transactions on Power Systems	57	0.64%	1.938	0.01922	4	IEEE
12	Applied Mathematics and Computation	56	0.63%	1.124	0.04288	24	Elsevier
13	Applied Soft Computing	56	0.63%	**2.415**	0.00373	6	Elsevier
14	IEEE Transactions on Antennas and Propagation	56	0.63%	**2.011**	0.03665	12	IEEE
15	Electric Power Systems Research	53	0.60%	1.259	0.00735	12	Elsevier
16	IEEE CEC 2006	52	0.59%	–	–	–	IEEE
17	Energy Conversion and Management	51	0.58%	1.944	0.01933	12	Elsevier
18	International Journal of Advanced Manufacturing Technology	51	0.58%	1.128	0.01263	24	Springer
19	IEEE CEC 2009	50	0.57%	–	–	–	IEEE
20	IEEE CCDC 2008	42	0.48%	–	–	–	IEEE
21	International Journal of Innovative Computing Information and Control	42	0.48%	**2.932**	0.00435	12	Kyushu Tokai University
22	IEEE SIS 2008	41	0.46%	–	–	–	IEEE
23	Engineering Applications of Artificial Intelligence	40	0.45%	1.444	0.00436	8	Elsevier
24	IEEE Transactions on Evolutionary Computation	40	0.45%	**4.589**	0.00860	6	IEEE
25	International Journal of Electrical Power and Energy Systems	39	0.44%	1.613	0.00362	10	Elsevier
26	Progress In Electromagnetics Research (PIER)	39	0.44%	**3.763**	0.00839	11	EMW Publishing
27	IEEE Transactions on Magnetics	37	0.42%	1.061	0.03472	–	IEEE
28	IEEE ICIS 2009	36	0.41%	–	–	–	IEEE
29	International Review of Electrical Engineering (IREE)	35	0.40%	0.570	0.00031	–	Praise Worthy Prize
30	IEEE CCDC 2009	34	0.38%	–	–	–	IEEE

(a) 2009 (b) 2010 (c) All

Figure 9. TagCloud [12] of PSO literature

the keywords can provide insights into research trends within PSO research and help to identify specific small research topic of interest.

IV. CONCLUSIONS

Since its introduction in 1995, PSO has enjoyed a great deal of popularity over the recent years in the research community. In this paper a scientometric study on the PSO research literature (2000-2010) was presented. Publication records were collected using the online Web of Knowledge (Thomson Reuters ISI), to carry out a bibliometric analysis, identifying distribution of authorship, co-authorship, citations and references, as well as top journals publishing PSO research. Frequency of keywords from the articles' title, was used to create TagClouds and get insights into research trends and fields of applications.

Comparative bibliometric studies with other conventional and recent optimization methods will carried out. This current study will help investigate PSO-based framework for research in Brain-Computer Interface (BCI) [15].

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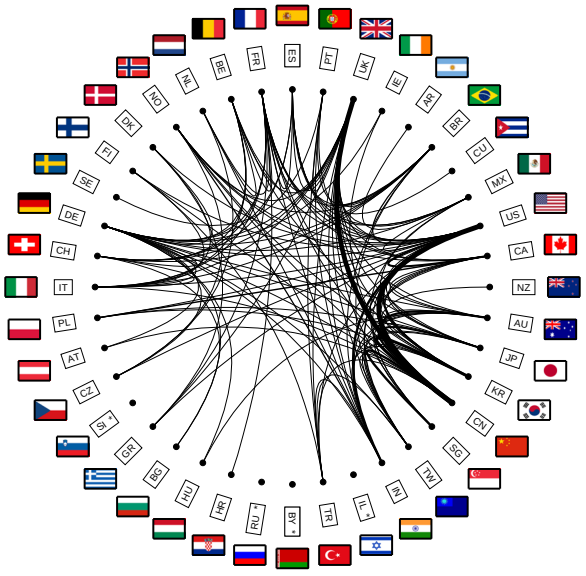

Figure 7. Countries collaboration network

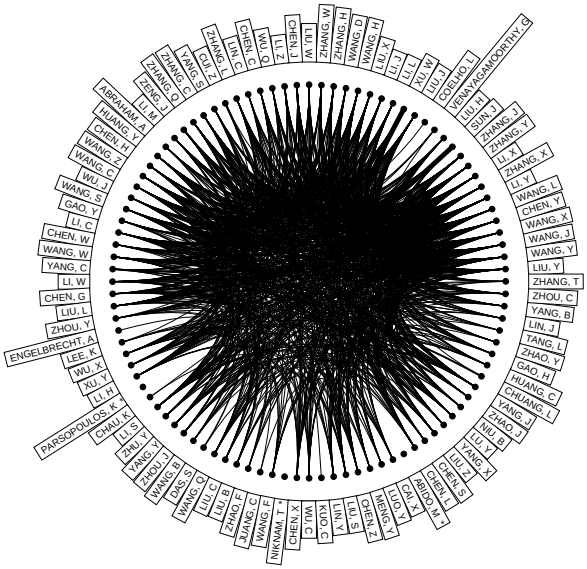

Figure 8. PSO researchers collaboration network

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