Bibliometric Analysis of Near-Infrared Spectroscopy (NIRS) Research 1995-2010

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Abstract—Near-Infrared Spectroscopy (NIRS) research has progressed over the last few decades. To assess its potential for biomedical applications, a bibliometric analysis on the NIRS research literature from 1995 to 2010 has been carried out and presented here. Using the Thomson Reuters Web of Science (WoS), a large corpus of papers have been retrieved and analyzed for bibliometrics. Growth of literature, authorship, citation and references, journals, as well as international collaborations were examined. Keyword occurrence analysis was performed on the articles' title to identify popular research topics, visually shown as TagClouds, to give insights into potential research trends. This study is helping future research and development of low-cost NIRS systems for attention/concentration monitoring and Brain-Computer Interface (BCI).

I. INTRODUCTION

Over the last few decades we have witnessed a significant progress in optics research especially in the field of for Near-Infrared Spectroscopy (NIRS), with a large variety of applications in testing the quality of food and beverages [1], in medicine and biomedical with stroke rehabilitation [2], study of neonatal brains [3]. A good review can be found in [4].

In this paper, the state-of-the-art in NIRS research literature, published over the last 15 years, is examined from a bibliometric point of view. This study aims to provide a comprehensive review of NIRS research to help future investigations into low-cost NIRS systems for Brain-Computer Interface (BCI) [5][6] and attention/concentration monitoring [7].

The remainder of the paper is organized as follows. In Section II, the search procedure is briefly described. In Section III, results of the bibliometric analysis are presented. Finally, we conclude the paper in Section IV.

II. PROCEDURE

The Thomson Reuters Web of Science (WoS) was used to retrieve records using the following query: NIRS as topic or in the title. This resulted in a large number of publications from optics and medical research and many other fields of research. Full records were saved as text for each year, including detailed author information with affiliation, title and abstract, list of references, citation count, references, etc. Scripts were used to extract and build useful bibliometric measures from the various fields associated with specific tags (AU: authors, TI: title, TC: citations, etc.).



Fig. 1. Growth of the NIRS research literature

III. RESULTS

A. Growth of literature

The growth of NIRS research literature over the last 15 years is shown in Figure 1. It can be fitted using a power law in the form of $N = a \times x^b$ show some nearly linear characteristic, with a=11.7972 and b=1.9698 (goodness-of-fit R^2 =0.9965).

B. Types of document

The NIRS research literature, from 1995 to 2010, consists of different types of documents including: 2063 articles (73.26%), 557 proceedings papers (19.78%), 90 meeting abstracts (3.20%), 86 reviews (3.05%), 12 editorial materials (0.43%), 5 letters (0.18%), 3 notes (0.11%), summing up to 2816 documents.

C. Authorship

A list of the most productive authors is given in Table I, ranked using their harmonic count [8], which puts greater emphasis on first authorship, thus reducing the bias of the *White Bull* effect [9]. The distribution of co-authorship is shown in Figure 2, with a clear peak for 4 co-authors (high

 TABLE I

 NIRS RESEARCHERS RANKED BY HARMONIC COUNTING

Rank	Name	NP	Harmonic	Arithmetic
1	HE, Y	71	19.758	35.317
2	VELASCO, L	21	11.909	20.500
3	COZZOLINO, D	21	9.763	17.250
4	MACNAB, A	29	9.296	16.900
5	LI, X	26	8.937	16.200
6	BLANCO, M	15	8.054	15.000
7	FALLGATTER, A	39	7.906	15.855
8	HERRMANN, M	24	7.669	16.733
9	EHLIS, A	32	7.281	16.233
10	GONZALEZ-MARTIN, I	16	7.031	14.333
11	PEREZ-MARIN, D	25	6.817	14.183
12	LITSCHER, G	14	6.674	11.250
13	WOLF, M	35	6.655	16.110
14	STOTHERS, L	17	6.603	11.417
15	SHAO, Y	14	6.372	11.333
16	REEVES, J	10	6.364	8.750
17	HOSHI, Y	12	6.021	8.593
18	BHAMBHANI, Y	15	6.019	9.226
19	WU, D	13	5.963	10.417
20	OBRIG, H	29	5.947	13.793
21	GARRIDO-VARO, A	31	5.754	12.026
22	COLIER, W	24	5.741	12.150
23	FONT, R	12	5.652	12.000
24	MALLEY, D	10	5.421	9.500
25	ELWELL, C	36	5.249	12.390
26	HAN, L	20	5.058	9.750
27	LIU, X	17	5.045	9.125
28	SAKATANI, K	19	4.998	11.508
29	QUARESIMA, V	20	4.837	10.333
30	BOAS, D	30	4.764	10.377
31	DING, H	25	4.700	10.512
32	DELPY, D	38	4.696	9.624
33	GAGNON, R	15	4.637	9.083
34	TACHTSIDIS, I	15	4.608	11.533
35	CEN, H	10	4.568	8.583

NP: number of publications

range 2 to 6). From Figure 3 on can observe higher number of papers published within the last few recent years.

D. Citations

In Figure 4 the distribution of citations is shown, it has a typical characteristic. Papers are on average cited 10.74 times (median 4.00 times), with some 25.99% of these publications never been cited. The paper with the highest number of citations is by A. Maki on *Spatial and temporal analysis of human motor activity using noninvasive NIR topography* [10], with 279 citations.

E. Country of origin

There are in total 59 countries contributing to the NIRS research literature (only 2732 entries from WoS have the field country of origin) and include USA (485, 17.75%), Japan (416, 15.23%), China (330, 12.08%), Germany (214, 7.83%), U.K. (168, 6.15%), Spain (162, 5.93%), Canada (120, 4.39%), Italy (117, 4.28%), France (101, 3.70%), Netherlands (68, 2.49%), Australia (60, 2.20%), Switzerland (58, 2.12%), Austria (48, 1.76%), Denmark (41, 1.50%), Brazil (38, 1.39%), Belgium (31, 1.13%), Korea (27, 0.99%), Sweden (24, 0.88%), etc. Using the country of the authors' affiliation, we obtain international collaborations between countries as shown in



Fig. 2. Number of papers versus number of co-authors



Fig. 3. Number of papers versus number of co-authors, on yearly basis

Figure 5. The main international collaborations are between USA, UK and Japan, with also France, Germany, and China.

F. Journals publishing NIRS

The list all the top 50 core journals publishing research in NIRS is presented in Table II. The journals with the highest Impact Factor (IF) [11] include *NeuroImage* (IF: 5.739), followed by *Journal of Cerebral Blood Flow and Metabolism* (IF: 5.457), *Intensive Care Medicine* (IF: 5.168), followed by *Critical Care* (IF: 4.931), *British Journal of Anaesthesia* (IF:



Fig. 4. Number of citations vs. number of papers (Loglog plot)



Fig. 5. International collaboration in NIRS research

3.827), Analytica Chimica Acta (IF: 3.757), Journal of Applied Physiology (IF: 3.732) and Medicine and Science in Sports and Exercise (IF: 3.707). Figure shows the IF versus EigenFactor (EF) [12] rankings.

G. Number of References

From 1995 to 2010 the yearly average number of references per article grew from 22.67 to 31.25. (median 19.99 to 26.57). Such increase is not surprising considering the use of today information systems for research publications. Figure 6 shows the evolution of the distribution over the years. The paper with



Fig. 6. Distribution of the NIRS articles' references

the highest number of references was written by Roggo and titled *A review of near infrared spectroscopy and chemometrics in pharmaceutical technologies* [13], with 240 references, followed by Hamaoka titled *Near–infrared spectroscopy/imaging for monitoring muscle oxygenation and oxidative metabolism in healthy and diseased humans* [14](with 236 references), then a paper by Dixon [15] with 196 references, and by Madsen with a paper titled *Near-infrared oximetry of the brain* [16], with 179 references.

H. Tag clouds

The Wordle tool [17] was used to generate TagClouds to help visualize the frequency of keywords (size proportional to frequency) from the NIRS research literature extracted from the papers' title, for all years and 2006 to 2010, as shown in Figure 7. Keywords such as *calibration* and *cerebral* seems to be two of the most important topics of interest found in the NIRS research literature.

IV. CONCLUSIONS

In this paper a bibliometric study of NIRS research literature, from 1995 to 2010, was presented. The examination of bibliometrics has revealed a matured and popular research field with a large variety of applications (medical, food and beverage, biology, to name only few), good citation counts and high profile journals. This study aimed to prepare future developments of low-cost NIRS systems for concentration monitoring [7] and Brain-Computer Interface (BCI) [5] for entertainment applications [18]. Future work will also investigate NIRS research trends using extensive study of the keywords, and its current limitations.

TABLE II NIRS CORE JOURNALS

Domlr	Nome of the journal	ND	0/	IE	EE	DE	Dublishan
		104	70	0.202	EF	10	
1	Spectroscopy and Spectral Analysis	124	4.41%	0.293	0.00175	12	Chinese Optical Society
2	NeuroImage	68	2.42%	5.739	0.16330	20	Elsevier
3	Journal of Biomedical Optics	60	2.13%	2.501	0.02173	6	SPIE
4	Animal Feed Science and Technology	4/	1.6/%	1.866	0.00900	32	Elsevier
5	Journal of Agricultural and Food Chemistry	46	1.63%	2.469	0.10371	24	ACS Publications
6	Journal of Applied Physiology	33	1.17%	3.732	0.06308	12	American Physiological Society
7	Pediatric Research	33	1.17%	2.607	0.02549	12	Lippincott Williams and Wilkins
8	Analytica Chimica Acta	31	1.10%	3.757	0.08105	52	Elsevier
9	European Journal of Applied Physiology	28	1.00%	2.047	0.01582	6	Springer
10	Applied Spectroscopy	25	0.89%	1.564	0.00978	12	Ingenta
11	Journal of Pharmaceutical and Biomedical Analysis	23	0.82%	2.453	0.02986	15	Elsevier
12	Physiological Measurement	18	0.64%	1.430	0.00692	12	IOP Publishing
13	Talanta	18	0.64%	3.290	0.04837	15	Elsevier
14	Crop Science	17	0.60%	1.735	0.01975	6	Crop Science Society of America
15	Medicine and Science in Sports and Exercise	17	0.60%	3.707	0.03492	12	Lippincott Williams and Wilkins
16	Neuroscience Letters	17	0.60%	1.925	0.06722	57	Elsevier
17	Oxygen Transport to Tissue XXXI	17	0.60%	-	-	-	Springer
18	Journal of Cerebral Blood Flow and Metabolism	16	0.57%	5.457	0.03025	12	Nature
19	Journal of Food Engineering	16	0.57%	2.313	0.02743	-	-
20	Neurological Research	16	0.57%	1.277	0.00846	10	Maney Publishing
21	Brain Research	15	0.53%	2.463	0.09506	60	Elsevier
22	Communications in Soil Science and Plant Analysis	15	0.53%	0.397	0.00409	22	Taylor and Francis
23	Meat Science	15	0.53%	1.954	0.01345	12	Elsevier
24	Spectroscopy: An International Journal	15	0.53%	0.986	0.00065	12	IOS Press
25	Agronomy Journal	14	0.50%	1.416	0.01258	6	American Society of Agronomy
26	Food Chemistry	14	0.50%	3.146	0.05883	24	Elsevier
27	Journal of Animal Science	14	0.50%	2.466	0.02451	12	American Society of Animal Science
28	Journal of infrared and millimeter waves	14	0.50%	0.74	-	_	Science Press
29	Physics in Medicine and Biology	14	0.50%	2.781	0.04485	-	IOP Press
30	International Journal of Industrial Ergonomics	13	0.46%	0.956	0.00275	6	Elsevier
31	Journal of The Science of Food and Agriculture	13	0.46%	-	-	15	Wiley
32	Cereal Chemistry	12	0.43%	1.314	0.00478	6	American Association of Cereal Chemists
33	Experimental Brain Research	12	0.43%	2.256	0.03741	24	Springer
34	Intensive Care Medicine	12	0.43%	5.168	0.03526	12	Springer
35	Journal of Pharmaceutical Sciences	12	0.43%	2.906	0.02294	12	AAPS
36	Oxygen Transport to Tissue XXIV	12	0.43%	-	-	-	Springer
37	Soil Biology and Biochemistry	12	0.43%	2.978	0.03334	12	Elsevier
38	Acta Paediatrica	11	0.39%	1.768	0.02188	12	Wiley
39	The Analyst	11	0.39%	3.272	0.01877	12	Royal Society of Chemistry
40	Biology of the Neonate	11	0.39%	1.984	0.00236	8	-
41	Critical Care	11	0.39%	4.931	0.03032	12	Springer
42	Early Human Development	11	0.39%	2.122	0.00858	12	Elsevier
43	4th International Conference on Photonics and Imaging in Biology and M	11	0.39%	-	-	_	-
44	Journal of Dairy Science	11	0.39%	2.460	0.03280	12	American Dairy Science Association
45	Journal of Trauma-Injury Infection and Critical Care	11	0.39%	2.626	0.04071	12	Lippincott Williams and Wilkins
46	Neuroscience Research	11	0.39%	2.986	0.03692	12	Elsevier
47	Oxygen Transport to Tissue XXX	11	0.39%	_	-	-	Springer
48	British Journal of Anaesthesia	10	0.36%	3.827	0.02248	12	Oxford University Press
49	European Journal of Vascular and Endovascular Surgery	10	0.36%	2.919	0.01688	12	Elsevier
50	Japanese Journal of Physical Fitness and Sports Medicine	10	0.36%	0.124	-	-	-

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Fig. 7. TagCloud [17] of NIRS literature



Fig. 8. Impact Factor (IF) versus EigenFactor (EF)

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