Analysis of Research Trends in Fractional Controller Using Latent Dirichlet Allocation

Pritesh Shah, *Member, IAENG,* Deepak Sharma, *Member, IAENG,* and Ravi Sekhar, *Member, IAENG*

***Abstract*—Complex industrial processes demand high performance control characteristics. Fractional order controller is more robust than the classical controllers generally used in industry. This paper presents an analysis of research trends in this ever-growing domain. Firstly, a corpus of 200 research articles published during 2014-19 was collected from selected journals. Latent Dirichlet Allocation methodology was applied on this literature data set for topic modeling. Optimal number of topics, average topic weights and topic prevalence per year were obtained. Distributions of topic proportions were generated for the selected journals and with respect to the author nationalities. In addition, continent and country-wise distribution of documents were also depicted. Primary results indicate that the topics of fractional order controller design and stability of fractional order system have been researched most in past years, but are on a declining trend. Fractional sliding control system and applications of fractional order systems are upward trending topics. Other topics like optimization of fractional order systems need more attention. In addition, journals publishing in the upward trending topics were identified. Journals publishing in a wide range of topics were also determined. It was found that almost 75% of all fractional controller publications during 2014-19 have Asian first authors, followed by European and African first authors. The majority of first authors belong to China (31%), India (19%), Iran(13%)and Turkey (8%). With regards to topic diversity, the Chinese and Indian authors have worked on the widest range of fractional controller topics, followed by the authors from Algeria, Iran, Portugal, Spain and Turkey. Researchers from other nations have focused on fewer topics.**

***Index Terms*—emerging trends, trend analysis, topic modeling, Latent Dirichlet Allocation, fractional order control, fractional sliding control**

I. Introduction

Future industrial systems are bound to get more complex, flexible, integrated and automated. This industrial 'evolution' will be supported by state of the art controllers in varied applications. Fractional controller is a promising controller having superior characteristics over the PID controllers generally found in the current industrial systems [1]. The fractional controller is based on fractional calculus, a branch of mathematics involving non integral orders of integration and derivation. It has profound applications in signal processing, system identification, control and more. [2], [3], [4], [5], [6], [7], [8]. The fractional differentiation-integral is defined as follows [9] -

$$ {}_aD_t^{\alpha} = \frac{1}{\Gamma(n-\alpha)} \int_a^t \frac{f^n(\tau)}{(t-\tau)^{\alpha-n+1}} d\tau \qquad (1) $$

Manuscript received Jan 14, 2020; revised June 25, 2020

Pritesh Shah and Ravi Sekhar are with Symbiosis Institute of Technology, Symbiosis International (Deemed University), Pune, India. E-mails: pritesh.shah@sitpune.edu.in, ravi.sekhar@sitpune.edu.in

Deepak Sharma is with Department of Computer Engineering, Amity School of Engineering & Technology, Amity University Uttar Pradesh, Noida, India. Email: deepak.btg@gmail.com

where,

$$ (n-1) \leq \alpha \leq n $$

a, t are integration limits, α is a real number and n is an integer.

Following is the mathematical representation of fractional controller [10].

$$ C(s) = \frac{U(s)}{E(s)} = K_P + \frac{K_I}{s^{\lambda}} + K_D S^{\mu}; \ (\lambda \text{ and } \mu \geq 0) \quad (2) $$

where, $C(s)$ is the controller output, $E(s)$ is the error signal, $U(s)$ is the control signal, λ is the order of integration, μ is the order of differentiator, K_p is the proportional constant gain, K_I is the integration constant gain and K_D is the derivative constant gain.

The fractional controller structure is shown in (Fig. 1).

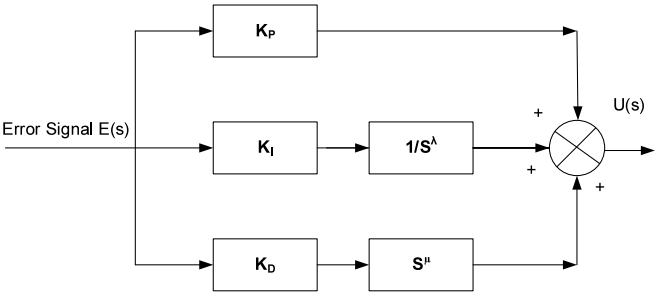

Fig. 1: Block diagram of fractional PID controller

This controller is more robust against fluctuations in tuning parameters and/or system variables [11], [12] due to its iso-damping property[13]. It also has five parameters (K_P, K_I, K_D, λ, μ) available for better tuning. The following section briefs upon the trend analysis methodology adopted in this work to identify research trends in fractional controllers.

II. Trend Analysis: Methodology

Fig.2 depicts the trend analysis methodology adopted in the current work [14], [15], [16]. A corpus of 200 articles was collected from select top journals, published during 2014-2019 for the current study. Table I lists the selected journals along with number of papers collected from each journal during the designated time period. After article collection, pre processing was carried out to remove noisy elements from the collected data set.

A. Pre-processing

Following steps were executed for data pre processing and corpus vector representations were generated for further analysis.

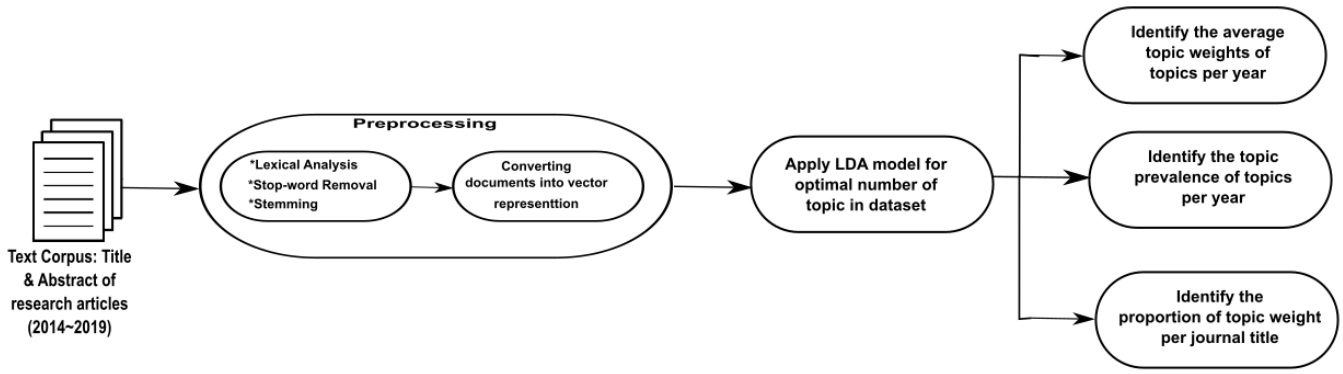

Fig. 2: Methodology of Trend Analysis

1) *Lexical analysis:* Firstly, the collected article titles and abstracts were tokenized for further analysis. Punctuation characters, quotation marks and numeric values were eliminated from the data set.
2) *Stop-word removal:* In the second step, standard English words / phrases identified as stop words by python package nltk [17] were removed.
3) *Stemming:* Thirdly, the document tokens generated by the lexical analysis were stemmed (inflected words converted to their base stems) using Porter Stemmer algorithm [18]. Gensim python library was utilised for document stemming and trend analysis [19].
4) *Vector representation of documents:* Finally, every article was represented by a sparse vector wherein vector elements depicted the mapped pairs of words and respective word counts. Sparse vectors were further compacted to TfIdf vectors using Eq.(3), where i, j and D are the term instance, document instance and total number of documents in corpus.

$$weight_{i,j} = frequency_{i,j} * \log \frac{D}{document_{freq_i}} \quad (3)$$

In the next phase, topic modelling algorithm was applied on the pre processed data set to identify trending topics from the collected articles.

B. Latent Dirichlet Allocation (LDA)

LDA is an efficient topic modelling methodology applicable in diverse domains [20]. It identifies latent ideas describing a given corpus [20], [21]. Each document is assumed to be composed of latent topics and every term in the document is assumed to be linked to one of these topics. The LDA generates topic models based on smoothing parameters (α, β) that affect topic distribution quality. In the present work, α was fixed at $\frac{50}{T}$, where T is the number of topics. Parameter β was fixed at 0.01 for all topic solutions. Before applying LDA, the number of identified topics needs to be optimal in order to ensure a good quality topic model. Too many topics may lead to losing out some important topics in the crowd. Too less topics may not generate meaningful topics at all. Therefore, a coherence model [22] was applied to decide the optimal number of topics in the data set of current study. This model evaluates the interpretability of topic models in the form of a coherence score. The topic model with the best coherence score is chosen as the one having optimum number of topics.

C. Average topic weights and prevalence of topics per year

In this step, the LDA model was applied to evaluate the trends of optimal topics over the selected time period. Each topic contains a set of *topic_words* and *word_weights* (probability of each *topic_word* in the topic). LDA computed the topic distribution of all articles and a list of *topic_ids* with respective *topic_weights* was generated for each article. Thereafter, average topic weights were determined over the time period under consideration based on the number of documents every year. Similarly, topic prevalence was computed by dividing the sum of topic occurrences by total documents per year.

D. Proportions of topic weights as per journals and countries

To identify the topics in which each journal is publishing articles, the proportions of significant topic weights for each journal were computed. This metric is an important tool for the researchers to successfully map their research topic to the appropriate journal significantly publishing articles of that topic. Similarly, proportions of topic weights were also computed as per the nationalities of the first authors of the articles. This distribution was computed to understand the topic wise focus of authors from different countries. The number of publications from different countries was also measured in the same way.

III. Results and Discussions

The following sections discuss the results of topic modelling and various useful insights into the research trends of fractional controller topics.

A. Dataset

For the current work, article data was collected from some well-known journals publishing high-quality research in the area of fractional order modeling and control. Titles and abstracts were collected from the electronic libraries of the selected journal articles. Only journal articles were included in this work to include significant research contributions. Corpus was prepared by collecting articles in the order

of publication dates, over a span of 6 years, i.e., from $2014 \sim 2019$. Table I lists the number of articles and corresponding journals included in the present study.

TABLE I: The number of articles included in this study

Sr. No.	Journal Name	Years	No. of Papers
1	ISA Transactions (TISA)	2014-2019	26
2	IFAC-PapersOnLine (IFAC)	2016-2018	23
3	Transactions Of The Institute Of Measurement And Control (TIMC)	2015-2019	19
4	International Journal of Control, Automation and Systems (IJCAS)	2015-2019	14
5	Journal of the Franklin Institute (JFI)	2014-2019	14
6	Nonlinear Dyanmics (springer) (SPND)	2014-2019	13
7	Arabian Journal for Science and Engineering (AJSC)	2017-2019	13
8	International Journal of Dynamics and Control (IJDC)	2017-2019	11
9	Mathematical Problems In Engineering (MPE)	2014-2018	11
10	Asian Journal Of Control (AJC)	2014-2019	9
11	Control Engineering Practice (CEP)	2016-2018	8
12	IEEE/CAA Journal of Automatica Sinica (IJAS)	2016-2019	7
13	Complexity (COMPL)	2014-2019	7
14	IET Control Theory & Applications (IETCTA)	2016-2018	6
15	IEEE Transactions on Industrial Electronics (ITIE)	2014-2018	5
16	Automatica (AUTO)	2014-2018	4
17	Journal Of Vibration And Control (JVC)	2016-2017	4
18	Neural Computing and Applications (NCA)	2018-2019	4
19	Neurocomputing (NECOMP)	2015	1
20	Advances in Difference Equations (ADE)	2018	1

B. Optimal number of topics

As per the coherence score analysis (Figure 4) executed by the topic coherence model, the optimal number of topics for the current study is 8. This topic count obtained the maximum coherence score among all other topic counts. This optimal count is also in agreement with the findings of similar studies in literature [23], [24].

C. Topic Trends Analyses

Figure 5 shows word-clouds of the 8 trending topics identified in the current study. Most of the topics are related to fractional order modeling and control as per the current study scope. Figure 6 displays count frequencies of the identified topics from the entire text dataset. Topic t_0 (fractional order controller design) has the highest frequency, followed by t_3 (stability of fractional order system), t_2 (fractional sliding control system), t_5 (applications of fractional order systems) and t_6 (optimization of fractional order systems). t_1 (robot trajectory tracking), t_4 (fractional order compensator) and t_7 (system modeling and control) exhibit very low count frequencies.

Thus, fractional order controller design has been the most investigated topic in the past few years. This area entails designing controller parameters for optimum process control using optimization tools like Genetic Algorithm. Relevant work in this areas includes: "A novel fractional-order model and controller for vibration suppression in flexible smart beam" [25]; "Fractional-order dynamic output feedback sliding mode control design for robust stabilization of uncertain fractional-order nonlinear systems" [26]; "Design of robust fractional-order controllers and prefilters for multivariable system using interval constraint satisfaction technique" [27] and others. However, topic weights and prevalence trends (Fig. 7 and 8) indicate that this area might have achieved its saturation point and is now on a downward trend. Possibly, this could be due to the continuous research carried out in this area for more than two decades now.

The second most researched topic is t_3, or stability of fractional order system. Stability is a critical aspect of controller design deployment in real world processes. Relevant work in this area includes: "The effects on stability region of the fractional-order PI controller for one-area time-delayed load-frequency control systems" [28]; "Fractional order control of the two-dimensional wave equation" [29] and "An analytical method on the stabilization of fractional-order plants with one fractional-order term and interval uncertainties using fractional-order PID controllers" [30]. However, this topic also seems to have hit a plateau (Fig. 7 and 8). This could be due to the stability theory now being well known and widely applied in various systems. The next topic in demand has been t_2, or fractional sliding control system. Recent samples in this area are: "Sliding mode based fractional-order iterative learning control for a nonlinear robot manipulator with bounded disturbance" [31]; "Practical tracking control of linear motor via fractional-order sliding mode" [32] and "A new fractional-order sliding mode controller via a nonlinear disturbance observer for a class of dynamical systems with mismatched disturbances" [33]. As per the topic weights and prevalence trends (Fig. 7 and 8), this trend promises to attract more investigations in the coming years. This can be ascribed to the unique characteristics of the sliding mode controller, such as the ability to uncertain and non linear systems. Journals prominently publishing in this area (Fig. 9) are JVC (Journal of Vibration and Control), NCA (Neural Computing and Applications), ADE (Advances in Difference Equations), AUTO (Automatica) and SPND (Springer Nonlinear Dynamics).

Almost equally important emerging trend is t_5, or the applications of fractional order systems. Researchers are finding newer and newer applications of fractional order control. Relevant articles include: "A new optimized fuzzy FOPI-FOPD controller for automatic generation control of electric power systems" [34]; "TLBO-Optimized FOPI Controller for Three-Phase Active Rectifier Using ZDPC Technique" [35] and "Multiobjective Optimization of a Fractional-Order PID Controller for Pumped Turbine Governing System Using an Improved NSGA-III Algorithm under Multiworking Conditions" [36]. Topic weights and prevalence analyses indicate that this is poised to become one of the most researched areas in fractional control (Fig. 7, 8) . Journals proportionately publishing more in this area are ADE (Advances in Difference Equations), AJSC (Arabian Journal for Science and Engineering) and COMPL (Complexity) 9. The t_6 topic, or the 'optimization of fractional order systems' may be identified for research investigations in the coming years

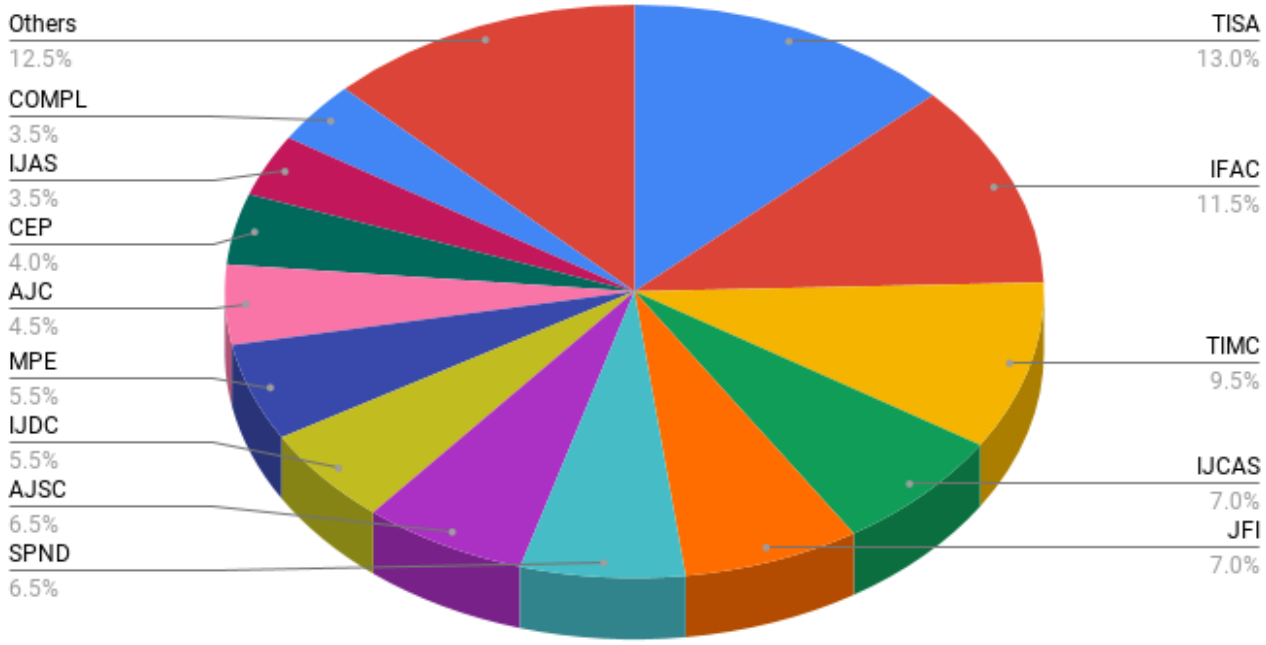

Fig. 3: Chart for number of paper selected from various Journal

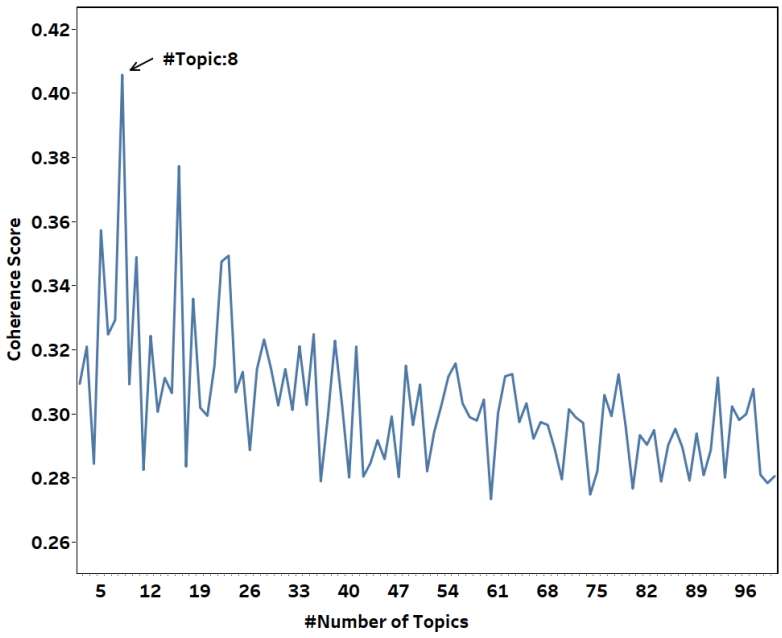

Fig. 4: Optimal number topics vs Coherence score

due to its impact potential. As of now, its upward trend is moderate (Fig. 7 and 8). Relevant works on this topic include: "Fractional Order Controller Designing with Firefly Algorithm and Parameter Optimization for Hydroturbine Governing System" [37]; "A novel fractional-order PID controller for integrated pressurized water reactor based on wavelet kernel neural network algorithm" [38] and "Input dependent Nyquist plot for limit cycle prediction and its suppression using fractional order controllers" [39]. Researchers may investigate applications of novel metaheuristics and socio inspired optimization algorithms in controller designs.

The remaining topics t_1, t_4, t_7) do not seem to have caught

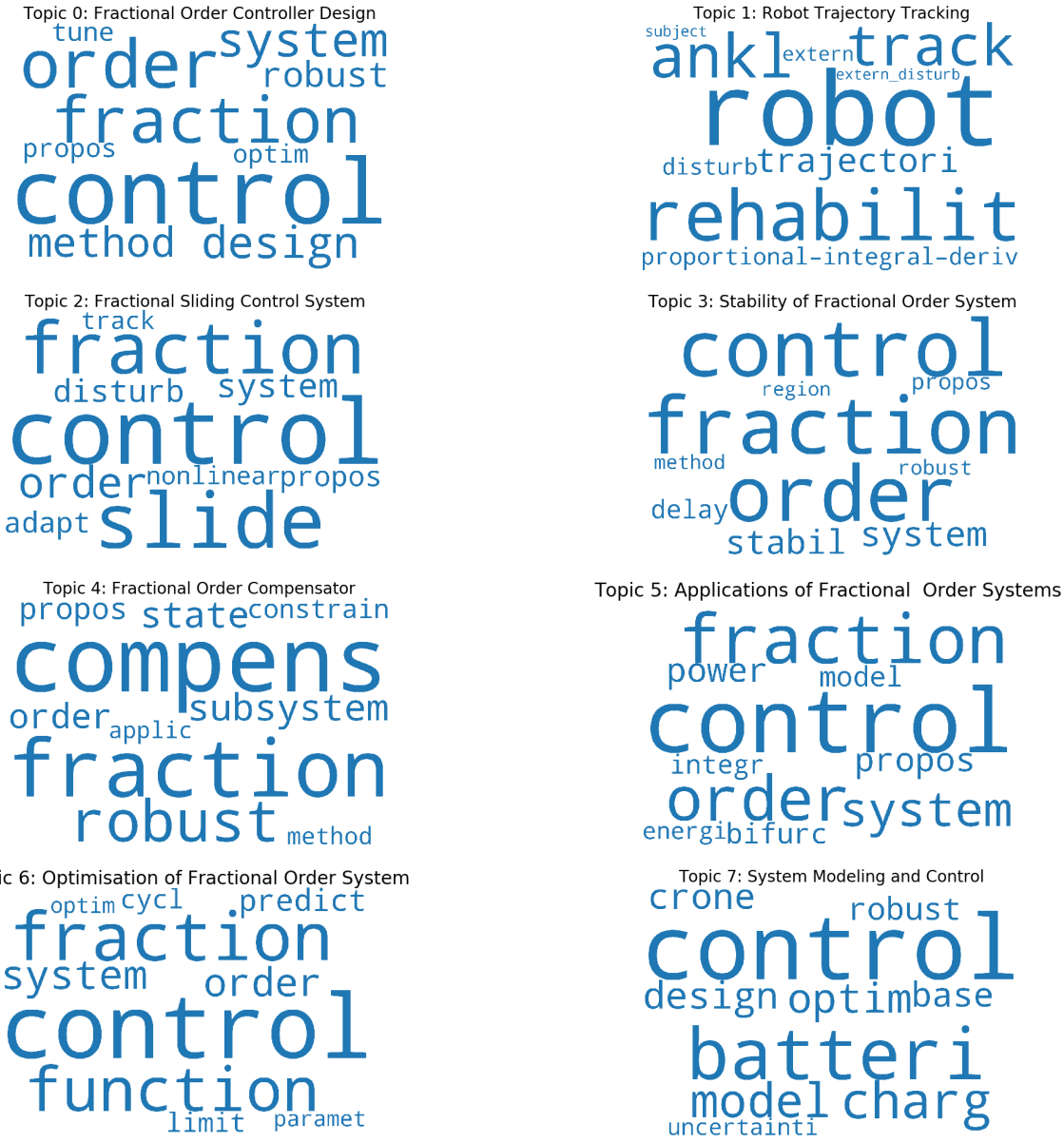

Fig. 5: Word-clouds of trending fractional controller topics

researchers' attention as much. The average weights and prevalence do not indicate optimistic trends for these topics (Fig. 7 and 8). Therefore, more exploratory investigations may be channeled towards these topics. "Fractional order based trajectory tracking control of an ankle rehabilitation robot" [40] is an example of possible articles on t_1 (robot trajectory tracking). Robotic applications demand intelligent controllers, hence a lot of scope is available for further research in this domain. Relevant articles for t_4 (fractional order compensator) include "fractional order compensator: Fractional-order sliding mode control of uncertain QUAVs with time-varying state constraints" [41] and "A simple method to design robust fractional-order lead compensator" [42]. Compensators are used to improve open loop plant system characteristics, which is handled well by fractional controllers on their own. This could be the reason behind low research volume in this topic. Finally, for t_7 (system modeling and control), "Design of a model-based fractional-order controller for optimal charging of batteries" [43] is a good example. This topic is bound to witness growing interest due to ever increasing applications of system modeling and control in physical systems.

Fig. 9 shows the proportionate topic distributions of articles published in each of the selected journals during 2014-19. It may be observed that journals like TIMC (Transactions of The Institute of Measurement And Control), SPND (Nonlinear Dyanmics (springer)) and IJCAS (International Journal of Control, Automation and Systems) have a good proportionate mix of articles related to as many as six topics. Other journals such as IFAC (IFAC-PapersOnLine), MPE (Mathematical Problems In Engineering), JVC (Journal Of Vibration And Control), AJSC (Arabian Journal for Science and Engineering), JFI (Journal of the Franklin Institute) and IJAS (IEEE/CAA Journal of Automatica Sinica) also have articles related to five or more topics, but in skewed proportions. Remaining journals have articles related to four or less topics.

Fig. 10 shows the proportionate topic distributions across first author nationalities. Fig. 11 shows the relative number

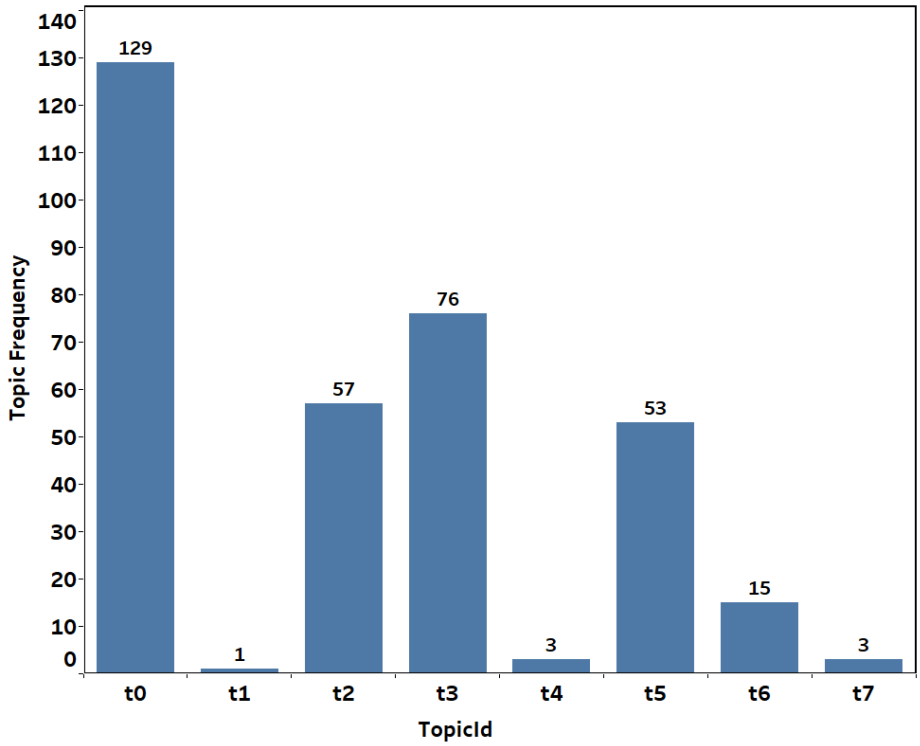

Fig. 6: Topic Id Vs Topic frequency

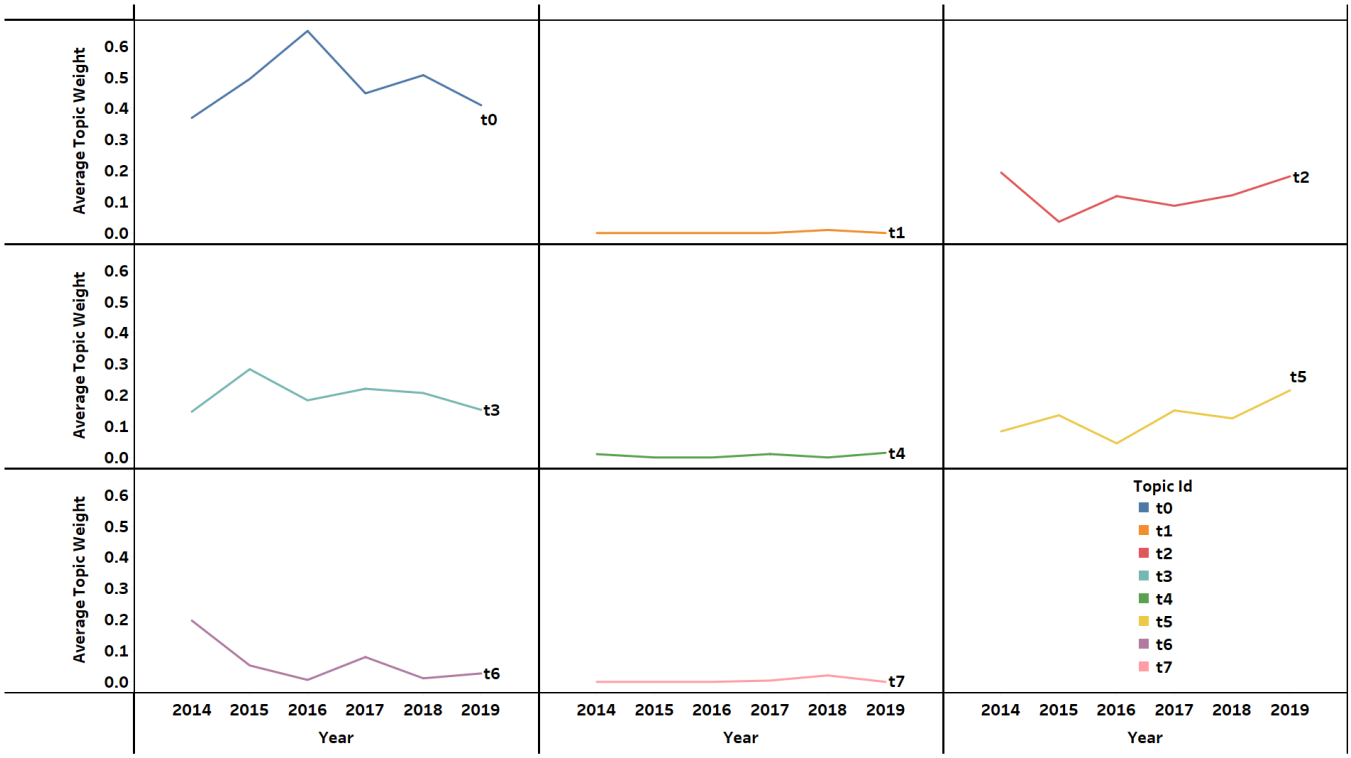

Fig. 7: Average topic weights of topic per year

of article publications as per the first author nationalities. The exact number of country-wise publications (top 20 nations) are listed in the table II and Fig. 12 shows percentage of publications as per the continents. This, it is clearly evident that maximum publications in fractional controller are having first authors from Asia, followed by Europe and Africa. In fact, most of them belong to either China or India. As a result, Chinese and Indian authors have been able to work on the widest range of fractional controller topics (six or more). Authors from Algeria, Iran, Portugal, Spain and Turkey have also investigated a decent diversity of topics (four to five). Researchers from other countries seem to have focused on fewer topics, with authors from countries like the Ethiopia, Malaysia, Saudi Arabia and Singapore working more on

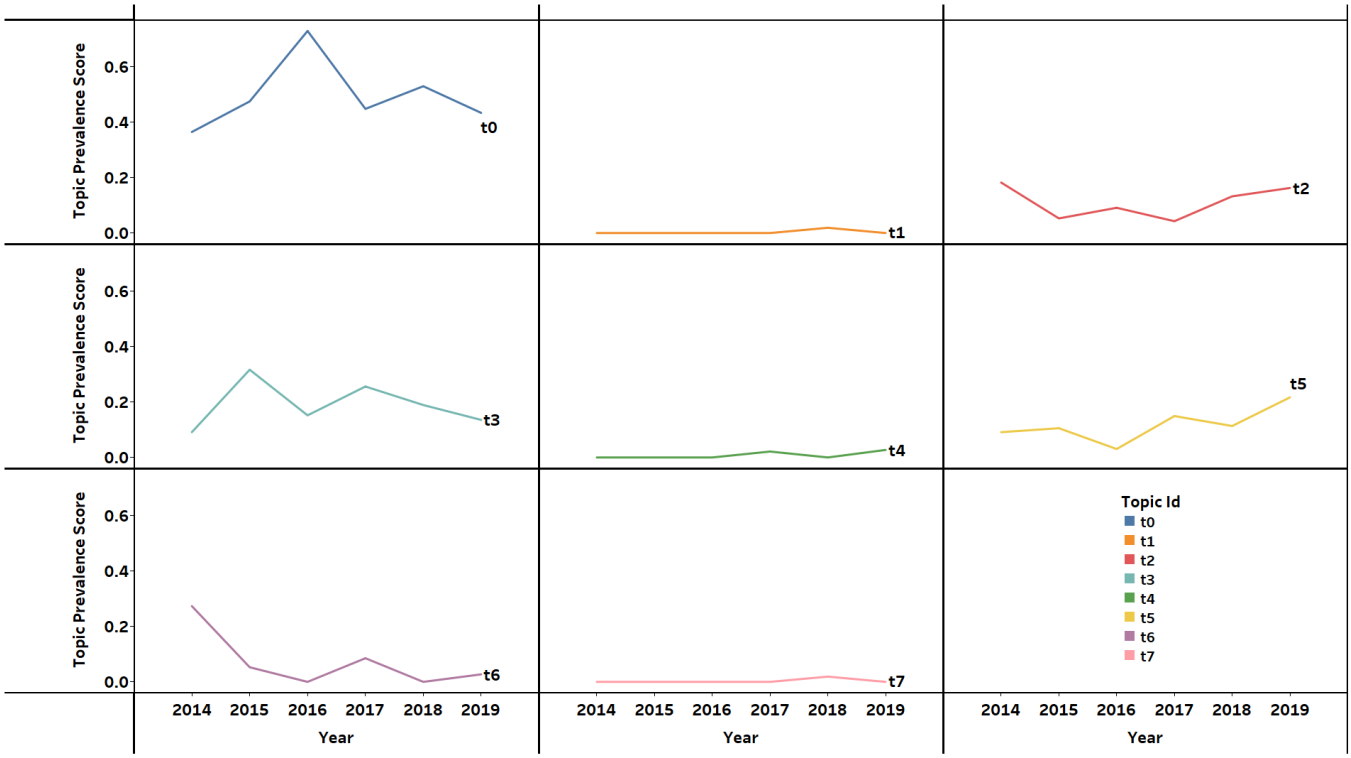

Fig. 8: Topic prevalence of topics per year

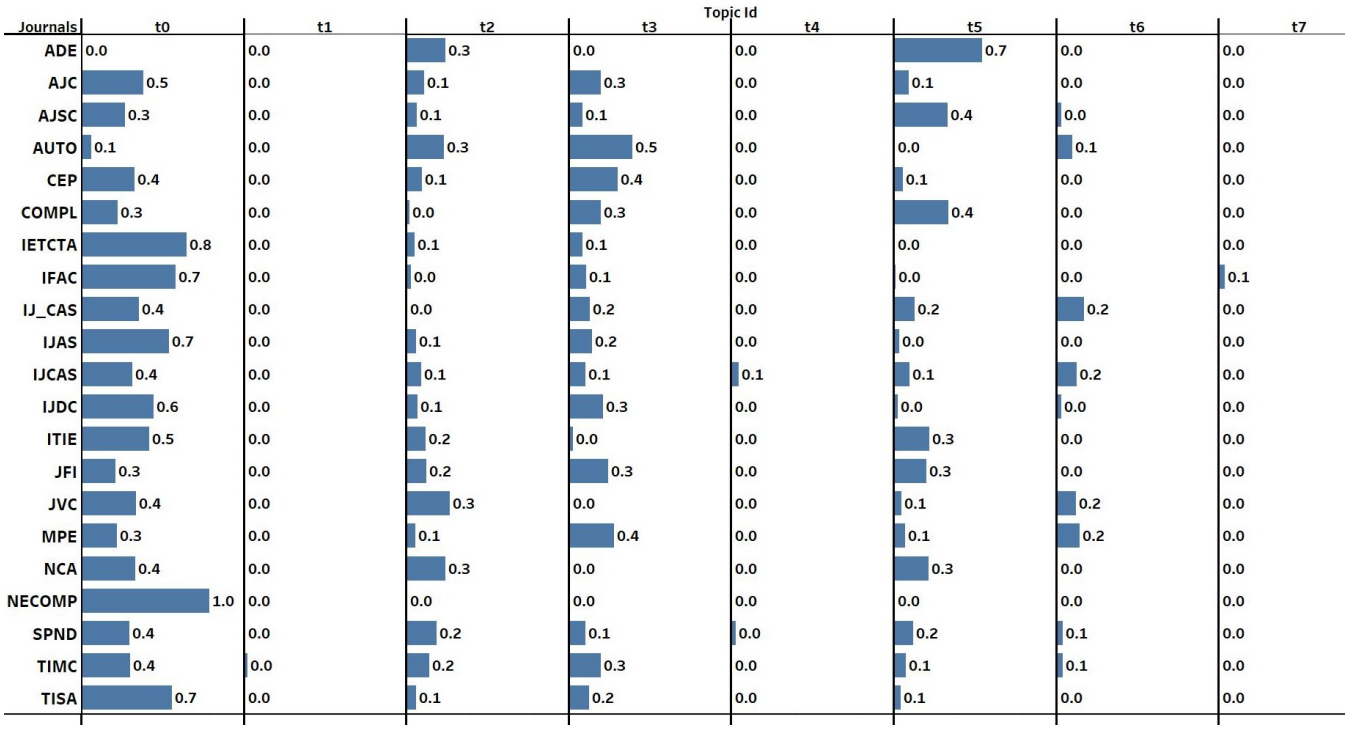

Fig. 9: Proportions of topics in each journal title

topic t_5, applications of the fractional order systems.

IV. Conclusions

In this paper, trends in fractional order control were analysed using Latent Dirichlet Allocation approach. A corpus of 200 research articles published during 2014-19 from leading journals was collected for this purpose. The collected literature data set was pre-processed using lexical analysis, stop word removal, word stemming and vector representations of documents. Thereafter, the LDA was applied to obtain the optimal number of topics (8), average topic weights per year, topic prevalence per year, proportions of topic weights per journal and topic weight proportions as per nationalities of the first authors. Furthermore, number of documents per journal, number of documents per country and their percent distribution across continents was also depicted

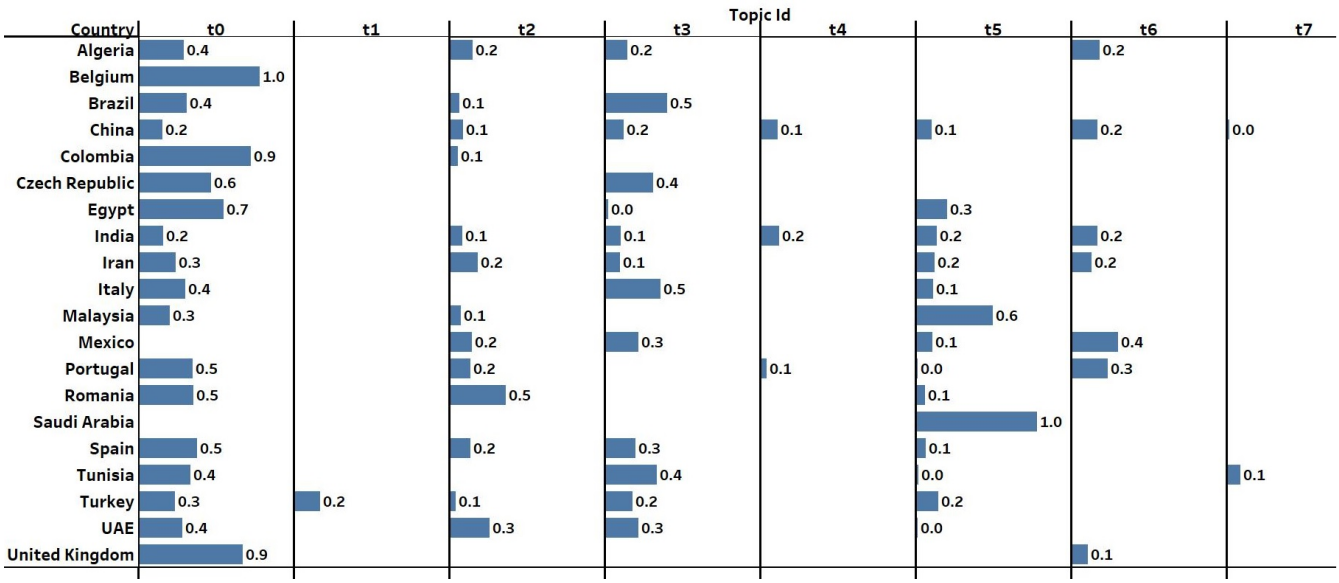

Fig. 10: Proportions of topics in each country

TABLE II: Fractional Controller Domain Publications (2014-19) in Selected Journals (Table 1): Top 20 Countries

Rank	Country Name	ISO Code	No. of Publications	Percentage
1	China	CHN	60	31%
2	India	IND	38	19%
3	Iran	IRA	25	13%
4	Turkey	TUR	15	8%
5	Algeria	DZA	9	5%
6	Spain	ESP	6	3%
7	Mexico	MEX	5	3%
8	Romania	ROU	5	3%
9	Tunisia	TUN	4	2%
10	Belgium	BEL	3	2%
11	Italy	ITA	3	2%
12	Portugal	PRT	3	2%
13	Saudi Arabia	SAU	3	2%
14	Czech Republic	CZE	2	1%
15	Malaysia	MYS	2	1%
16	UAE	ARE	2	1%
17	United Kingdom	GBR	2	1%
18	Brazil	BRA	1	1%
19	Colombia	COL	1	1%
20	Egypt	EGY	1	1%

to better understand research focus (on topics) and research outputs (number of documents) of researchers from all over the world. Primary results of trend analyses on fractional controller research indicate that -

1) Fractional order controller design is the most investigated research area in recent years. However, researchers' interest in this topic is on a declining trend.
2) Stability of fractional order system is the second most researched topic. Its trends are flat and may not attract further increment in interest in future.
3) The third most researched topic is fractional sliding control system with a steadily rising trend. More research is expected in this area. Journals prominently publishing in this area are Journal of Vibration and Control, Neural Computing and Applications, Advances in Difference Equations, Automatica and Springer Nonlinear Dynamics. Researchers from the UAE, Romania and Pakistan have proportionately worked more in this area.
4) Applications of fractional order systems is the fastest growing topic. Trends indicate that in future, more and more applications of fractional order systems will be reported. Journals proportionately publishing more in this area are Advances in Difference Equations, Arabian Journal for Science and Engineering and Complexity. Researchers from Malaysia, Saudi Arabia and Singapore seem to be proportionately more focused on this area.
5) Topics requiring more research attention are 'optimization of fractional order systems', 'robot trajectory tracking', 'fractional order compensators' and 'system modeling and control'.
6) Journals like TIMC (Transactions Of The Institute Of Measurement And Control), SPND (Nonlinear Dyanmics (springer)) and IJCAS (International Journal of Control, Automation and Systems) publish articles related to the widest range of fractional controller topics.
7) Almost 75% of all fractional controller research during 2014-19 has Asian first authors, followed by European

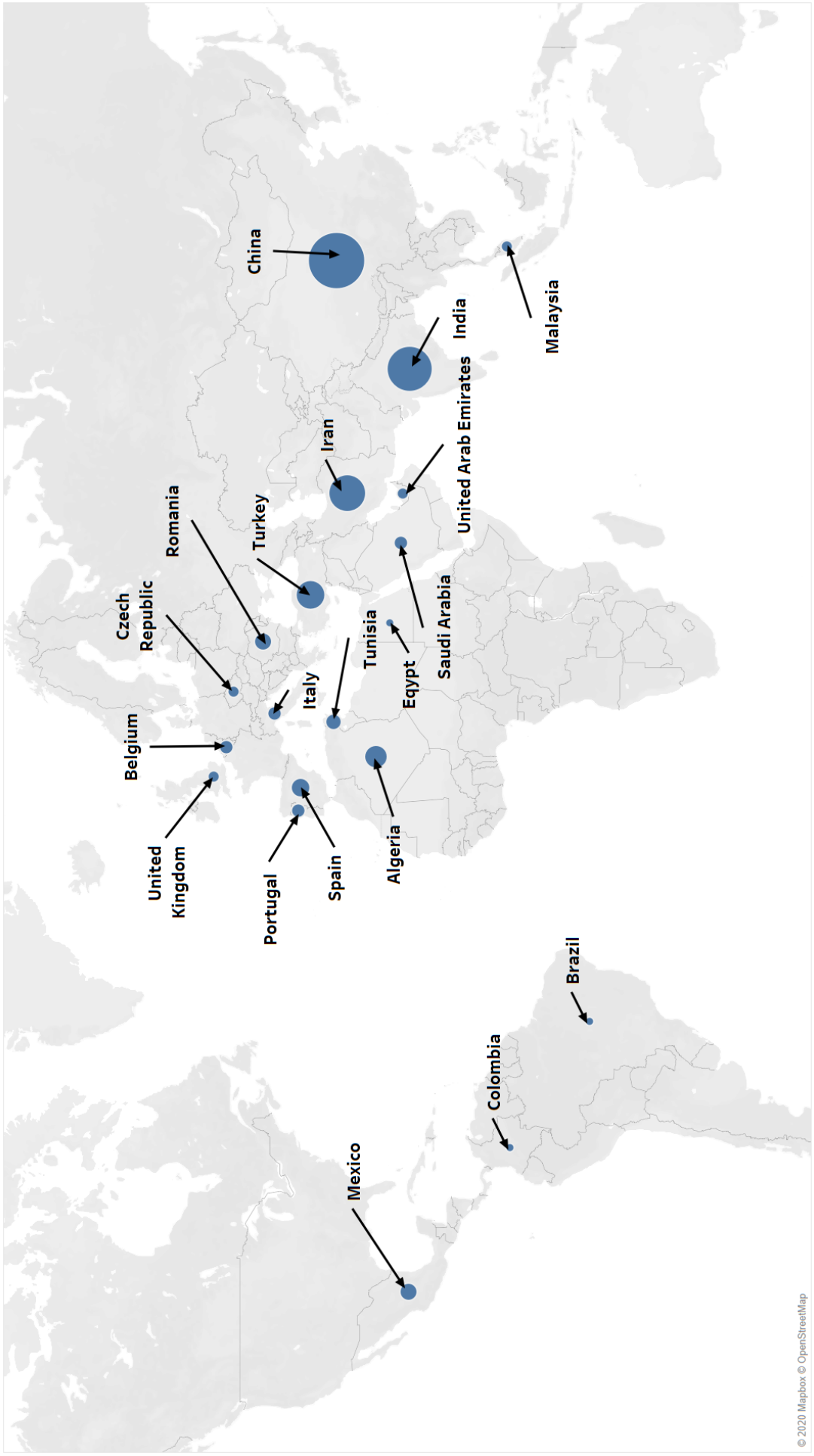

Fig. 11: Country wise articles published in fractional controller domain: 2014-19

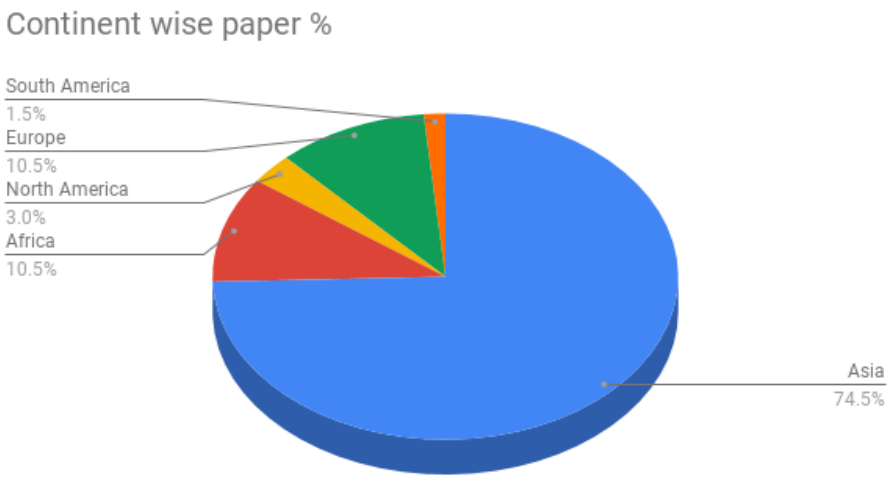

Fig. 12: Continent wise paper distribution in percentage

and African first authors. Of these, the majority of first authors belong to China (31%), India (19%), Iran(13%) and Turkey (8%).

8) With regards to topic diversity, the Chinese and Indian authors have worked on the widest range of fractional controller topics, followed by the authors from Algeria, Iran, Portugal, Spain and Turkey. Researchers from other nations have focused on fewer topics.

REFERENCES

[1] Y. Luo, Y. Q. Chen, C. Y. Wang, and Y. G. Pi, "Tuning fractional order proportional integral controllers for fractional order systems," *Journal of Process Control*, vol. 20, no. 7, pp. 823–831, Aug. 2010.

[2] X. Zhang and D. Yuan, "A niche ant colony algorithm for parameter identification of space fractional order diffusion equation," *IAENG International Journal of Applied Mathematics*, vol. 47, no. 2, pp. 197–208, 2017.

[3] E. Rusyaman, K. Parmikanti, D. Chaerani, and S. Supian, "The fractional relationship between viscosity and surface tension on lubricating oils," *IAENG International Journal of Applied Mathematics*, vol. 50, no. 1, pp. 160–164, 2020.

[4] M. Li, L. Wang, and Y. Liu, "Generalized hat functions method for solving fractional integro-differential equations of bratu-type," *IAENG International Journal of Computer Science*, vol. 44, no. 1, pp. 105–111, 2017.

[5] S. O. Edeki, O. O. Ugbebor, and E. A. Owoloko, "Analytical solution of the time-fractional order black-scholes model for stock option valuation on no dividend yield basis," *IAENG International Journal of Applied Mathematics*, vol. 47, no. 4, pp. 407–416, 2017.

[6] Z. Dahmani, M. A. Abdellaoui, and N. Bedjaoui, "Applications of fixed point theorems for coupled systems of fractional integro-differential equations involving convergent series," *IAENG International Journal of Applied Mathematics*, vol. 45, no. 4, pp. 273–278, 2015.

[7] H. Miao, X. Abdurahman, Z. Teng, and C. Kang, "Global dynamics of a fractional order HIV model with both virus-to-cell and cell-to-cell transmissions and therapy effect," *IAENG International Journal of Applied Mathematics*, vol. 47, no. 1, pp. 75–81, 2017.

[8] R. Sekhar, T. P. Singh, and P. Shah, "ARX/ARMAX modeling and fractional order control of surface roughness in turning nano-composites," in *2019 International Conference on Mechatronics, Robotics and Systems Engineering (MoRSE)*, 2019, pp. 97–102.

[9] P. Shah and R. Sekhar, "Closed loop system identification of a DC motor using fractional order model," in *2019 International Conference on Mechatronics, Robotics and Systems Engineering (MoRSE)*, 2019, pp. 69–74.

[10] P. Shah and S. Agashe, "Review of fractional PID controller," *Mechatronics*, vol. 38, pp. 29–41, 2016.

[11] P. Shah, R. Sekhar, and S. Agashe, "Application of fractional pid controller to single and multi-variable non-minimum phase systems," *International Journal of Recent Technology and Engineering*, vol. 8, no. 2, pp. 2801–2811.

[12] P. Shah, S. Agashe, and A. J. Kulkarni, "Design of a fractional $PI^{\lambda}D^{\mu}$ controller using the cohort intelligence method," *Frontiers of Information Technology & Electronic Engineering*, vol. 19, no. 3, pp. 437–445, Mar 2018.

[13] I. Podlubny, "Fractional-order systems and fractional-order controllers," *UEF-03-94, Inst. Exp. Phys, Slovak Acad. Sci., Kosice*, pp. 1–24, 1994.

[14] D. Sharma, B. Kumar, and S. Chand, "A trend analysis of machine learning research with topic models and mann-kendall test," *International Journal of Intelligent Systems and Applications*, vol. 11, no. 2, p. 70, 2019.

[15] H. Bunyamin, Heriyanto, S. Novianti, and L. Sulistiani, "Topic clustering and classification on final project reports: A comparison of traditional and modern approaches," *IAENG International Journal of Computer Science*, vol. 46, no. 3, pp. 506–511, 2019.

[16] D. Huynh, D. Tran, and W. Ma, "Contextual analysis for the representation of words," *IAENG International Journal of Computer Science*, vol. 41, no. 2, pp. 148–152, 2014.

[17] E. Loper and S. Bird, "Nltk: the natural language toolkit," *arXiv preprint cs/0205028*, 2002.

[18] M. F. Porter, "An algorithm for suffix stripping," *Program*, vol. 14, no. 3, pp. 130–137, 1980.

[19] R. Rehurek and P. Sojka, "Software framework for topic modelling with large corpora," in *In Proceedings of the LREC 2010 Workshop on New Challenges for NLP Frameworks*. Citeseer, 2010.

[20] D. M. Blei, A. Y. Ng, and M. I. Jordan, "Latent dirichlet allocation," *Journal of machine Learning research*, vol. 3, no. Jan, pp. 993–1022, 2003.

[21] M. Kato, T. Kosaka, A. Ito, and S. Makino, "An algorithm for fast calculation of back-off n-gram probabilities with unigram rescaling," *IAENG International Journal of Computer Science*, vol. 36, no. 4, pp. 284–288, 2009.

[22] M. Röder, A. Both, and A. Hinneburg, "Exploring the space of topic coherence measures," in *Proceedings of the eighth ACM international conference on Web search and data mining*. ACM, 2015, pp. 399–408.

[23] R. B. Bradford, "An empirical study of required dimensionality for large-scale latent semantic indexing applications," in *Proceedings of the 17th ACM conference on Information and knowledge management*. ACM, 2008, pp. 153–162.

[24] A. Sidorova, N. Evangelopoulos, J. S. Valacich, and T. Ramakrishnan, "Uncovering the intellectual core of the information systems discipline," *Mis Quarterly*, pp. 467–482, 2008.

[25] C. I. Muresan, S. Folea, I. R. Birs, and C. Ionescu, "A novel fractional-order model and controller for vibration suppression in flexible smart beam," *Nonlinear Dynamics*, vol. 93, no. 2, pp. 525–541, 2018.

[26] S. Dadras and H. R. Momeni, "Fractional-order dynamic output feedback sliding mode control design for robust stabilization of uncertain

fractional-order nonlinear systems," *Asian Journal of Control*, vol. 16, no. 2, pp. 489–497, 2014.

[27] M. D. Patil, P. Nataraj, and V. A. Vyawahare, "Design of robust fractional-order controllers and prefilters for multivariable system using interval constraint satisfaction technique," *International Journal of Dynamics and Control*, vol. 5, no. 1, pp. 145–158, 2017.

[28] V. Çelik, M. T. Özdemir, and G. Bayrak, "The effects on stability region of the fractional-order pi controller for one-area time-delayed load–frequency control systems," *Transactions of the Institute of Measurement and Control*, vol. 39, no. 10, pp. 1509–1521, 2017.

[29] L. Sirota and Y. Halevi, "Fractional order control of the two-dimensional wave equation," *Automatica*, vol. 59, pp. 152–163, 2015.

[30] Z. Gao, "An analytical method on the stabilization of fractional-order plants with one fractional-order term and interval uncertainties using fractional-order pi λ d μ controllers," *Transactions of the Institute of Measurement and Control*, vol. 40, no. 15, pp. 4133–4142, 2018.

[31] I. Ghasemi, A. Ranjbar Noei, and J. Sadati, "Sliding mode based fractional-order iterative learning control for a nonlinear robot manipulator with bounded disturbance," *Transactions of the Institute of Measurement and Control*, vol. 40, no. 1, pp. 49–60, 2018.

[32] G. Sun, L. Wu, Z. Kuang, Z. Ma, and J. Liu, "Practical tracking control of linear motor via fractional-order sliding mode," *Automatica*, vol. 94, pp. 221–235, 2018.

[33] S. Pashaei and M. Badamchizadeh, "A new fractional-order sliding mode controller via a nonlinear disturbance observer for a class of dynamical systems with mismatched disturbances," *ISA transactions*, vol. 63, pp. 39–48, 2016.

[34] Y. Arya, "A new optimized fuzzy fopi-fopd controller for automatic generation control of electric power systems," *Journal of the Franklin Institute*, 2019.

[35] A. Kumar and G. Srungavarapu, "Tlbo-optimized fopi controller for three-phase active rectifier using zdpc technique," *Arabian Journal for Science and Engineering*, pp. 1–15, 2019.

[36] C. Zhang, T. Peng, C. Li, W. Fu, X. Xia, and X. Xue, "Multiobjective optimization of a fractional-order pid controller for pumped turbine governing system using an improved NSGA-III algorithm under multiworking conditions," *Complexity*, vol. 2019, 2019.

[37] L. Junyi and Q. Chen, "Fractional order controller designing with firefly algorithm and parameter optimization for hydroturbine governing system," *Mathematical Problems in Engineering*, vol. 2015, 2015.

[38] Y.-x. Zhao, X. Du, and G.-l. Xia, "A novel fractional-order PID controller for integrated pressurized water reactor based on wavelet kernel neural network algorithm," *Mathematical Problems in Engineering*, vol. 2014, 2014.

[39] S. Perumal and N. Selvaganesan, "Input dependent nyquist plot for limit cycle prediction and its suppression using fractional order controllers," *Transactions of the Institute of Measurement and Control*, p. 0142331219841113, 2019.

[40] M. S. Ayas, I. H. Altas, and E. Sahin, "Fractional order based trajectory tracking control of an ankle rehabilitation robot," *Transactions of the Institute of Measurement and Control*, vol. 40, no. 2, pp. 550–564, 2018.

[41] C. Hua, J. Chen, and X. Guan, "Fractional-order sliding mode control of uncertain quavs with time-varying state constraints," *Nonlinear Dynamics*, vol. 95, no. 2, pp. 1347–1360, 2019.

[42] S. P. Jadhav, S. T. Hamde *et al.*, "A simple method to design robust fractional-order lead compensator," *International Journal of Control, Automation and Systems*, vol. 15, no. 3, pp. 1236–1248, 2017.

[43] S. Mohajer, P. Lanusse, J. Sabatier, and O. Cois, "Design of a model-based fractional-order controller for optimal charging of batteries," *IFAC-PapersOnLine*, vol. 51, no. 28, pp. 97–102, 2018.