Bibliometric Survey on Image Processing Techniques using Lattice Boltzmann Method for CFD Simulations

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Abstract: This bibliometric analysis aims to understand how Lattice Boltzmann Method could be a potential solver in integrating computational fluid dynamics with image segmentation smoothly. Cardiovascular diseases have been a major health problem in our society and have been an interesting topic for researchers to focus on. Computational Fluid dynamics (CFD) simulation on well segmented patient specific images could help the clinicians in diagnosing many cardiovascular diseases in the initial stages itself thereby avoiding surgery. This paper focuses on how various methods have been used since 1988 and been successfully implemented in subsequent years. The bibliometric analysis is done from Scopus and the research is based on 1726 published papers. The main purpose of this survey is to find out the research going on for the crucial problem of the society. This survey would therefore help us in analysing and estimating the type of work done and the amount of work done in this area and the future scope for the research to carry on. This study is very much effective and essential thereby giving a clear picture of the type of work going on and what new techniques could be used to make a CFD solver that could predict the hemodynamic behaviour and also the cardiovascular diseases at the initial stages.

Keywords: *Image processing, Lattice Boltzmann Method, Computational Fluid Dynamics and Hemodynamics*

1. Introduction

Cardiac abnormality accounts for many cardiovascular health problems of our society and so it has been an interesting topic by research analysts to focus on. It has even been the leading cause of death. Diagnostic modalities of cardiac dysfunction either invasive or non-invasive provide structural information but fail to provide the complete picture of the hemodynamic state which can act as potential performance indicators for determining the anatomical and functional analysis of cardiovascular abnormalities (Taylor & Figueroa, 2009)(Wong et al., 2017).This is where computational hemodynamics comes into play(Biffi et al., 2019). The areas that are diseased, plagued, or ruptured are strongly influenced by the blood flow

dynamics and also the geometry of the vessel. By modeling, we are trying to find out the regions that are likely to have cracks or have ruptured by taking patient-specific geometries of the vessels. Out of the total coronary diseases, 20% of it cannot be seen in a CT scan or MRI. 60 % of the time, our body can handle the stress of the arteries. 20 % of the cases lead to Stable Angina when there is high shear stress developed thereby leading to blockage. This could be monitored in a CT scan or MRI and hence doctors can identify it. 20% of the cases are such as during the expansion of the walls in the arteries or due to lower shear stress there is a possibility of rupture thereby leading to the acute coronary syndrome. This is of great concern as it cannot be shown in a CT scan or MRI. Simulation is the only rescue to find the patient's shear stress ((Koskinas et al., 2010)).

Accurate simulation of patient specific data can be done if the segmentation of image is accurate. Efficient segmentation techniques like the level set methods, graph partitioning methods help identify distinct regions more systematically (Varshney et al., 2009).Segmenting images derived from LBM could again be considered for segmentation as it could compress the image noise even after conserving edges of the images ((Y. Chen et al., 2007)(Z. Q. Wang et al., 2011). If image processing and CFD simulation could be put into the same platform then the analysis would be easy. An efficient numerical solver using the same lattice or network of image processing could be used in CFD to find out the basic parameters like velocity, wall shear stress, etc. which would help to understand its various causes and effects (Noël et al., 2017)Hence Lattice Boltzmann Method could be used as a platform where both image segmentation and CFD simulation could be worked upon (An et al., 2017).A unified computational model initiating from extraction of structure from radiological CT and MRI images to hemodynamics in one computation set up using LBM needs to be looked upon (Yu et al., 2014). An idea of parallel computing could also be focussed (Z. Wang et al., 2019) As a preliminary search , a bibliographic survey would give a clear picture on why one needs to focus on this research, and the type and amount of research already done in this area and what new could be added. We have taken a few keywords. There are few generalized keywords as well as specific key words results which has been compared. This paper would definitely give a clear picture on the various literature available on the giant database Scopus. In section 2 a bibliometric analysis is done followed by network analysis in section 3. Section 4 gives us the future scope of this paper followed by conclusion in section5

2. Bibliometric Analysis

2.1 Significant keywords

The data is from Scopus and there were combinations of keywords that were used. We had considered two types of keywords i.e Primary keyword and secondary keywords. Primary keywords include image processing and Lattice Boltzmann Method and secondary keywords include computational fluid dynamics and hemodynamics. Various combination of 'AND' and 'OR' were used in between the keywords and the results were analysed. Results are shown in Table 01. We see that as we go on refining our topic more specifically we see that the number of papers get reduced drastically from 1726 to only 5 papers. This paper focuses on the analysis of those 1726 papers.

Table 1: Significant keyword and their combinations
(Source: https://www.scopus.com/ (accessed on January 19, 2021)

S. No	Keywords	Search Results
1	IMAGE PROCESSING AND LATTICE BOLTZMANN METHOD OR COMPUTATIONAL FLUID AND DYNAMICS	1726
2	IMAGE AND PROCESSING AND LATTICE BOLTZMANN METHOD AND COMPUTATIONAL FLUID DYNAMICS OR HEMODYNAMICS	89
3	IMAGE AND PROCESSING AND LATTICE BOLTZMANN METHOD AND COMPUTATIONAL FLUID DYNAMICS AND HEMODYNAMICS	05

2.2 Publication trend Analysis

Year wise publication in the recent years have been analysed. Table 2 shows the number of publications that have been published from 2000 to 2021 in the field of image processing using Lattice Boltzmann method for CFD simulations. There an upward trend in the previous years followed by a flatness. We find that research have been gradually increasing over the years mostly during 2016, 17, and 18 and has been a decrease in the last two years though a consistency has been maintained. So one can focus more on the research in the area of image processing using this novice method (Lattice Boltzmann Method) to be used further in patient specific CFD simulations. Figure 1 shows the bar graph which tells us about the publications in the last 10 years. The publications have increased a lot in 2016, 2017 and 2018. Being a very social concern for research the graph shows an increasing trend over the recent years. The maximum publications was seen in the year 2017

Table 2: Publication trend from the year 2000 – 2021

Source: https://www.scopus.com/ (accessed on January 19, 2021)

Year	No. of Publications	Year	No. of Publications
2021	9	2010	89
2020	96	2009	115
2019	97	2008	107
2018	127	2007	53
2017	133	2006	40
2016	126	2005	40
2015	106	2004	48
2014	122	2003	36
2013	95	2002	21
2012	58	2001	22
2011	64	2000	21
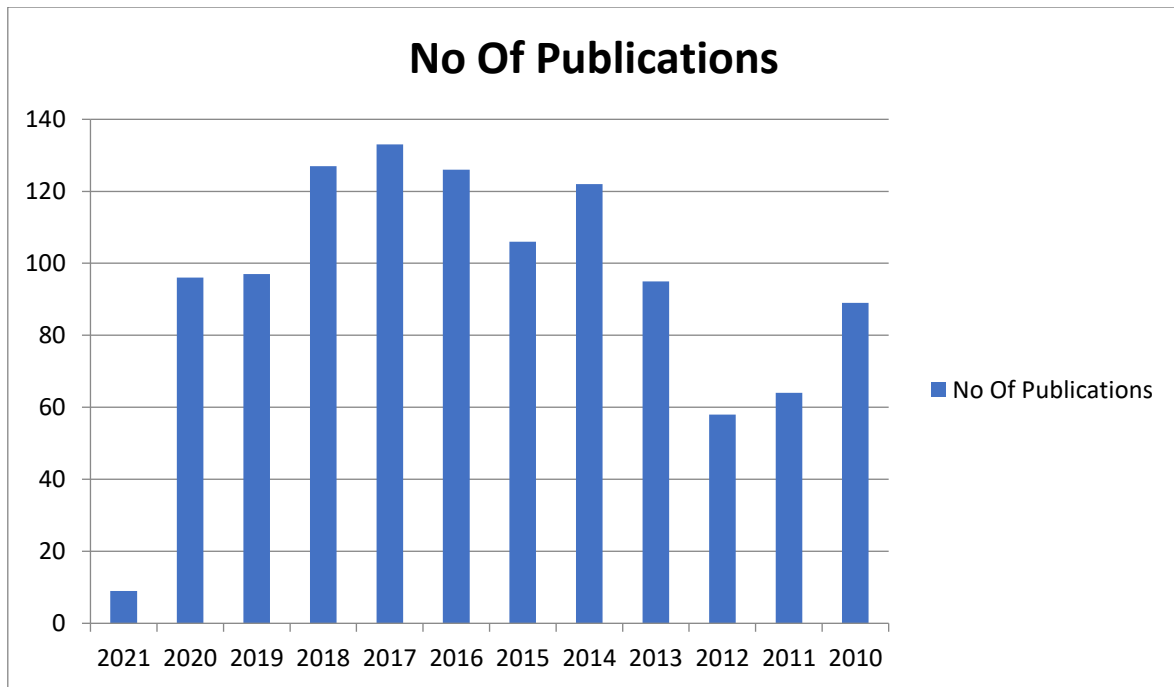
Figure 1: Year-wise trend of publication for the last 10 Years.
Source: https://www.scopus.com/ (accessed on January 19, 2021)

2.3 Countrywise Publication Trend analysis:

Table 3 shows the number of documents published in the field of image processing using Lattice Boltzmann method from the Scopus database. From the data collected we see that maximum research has been done in United States of America(539) followed by China(248) and Germany(182). We see that India has been lagging behind with only 42 publications. Thus we see that India needs to focus more on the current topic. As cardiac abnormalities have increased a lot in the recent years, a good research would definitely benefit the society. Figure 2 clearly shows the country wise location clusters in the world map. The top 26 countries with the number of documents have been shown in the table 3.

Table 3: Country-wise number of documents published
Source: https://www.scopus.com/ (accessed on January 13, 2021)

Name of Country	No. of documents	Name of country	No. of documents
United States	539	Switzerland	32
China	248	Singapore	29

Germany	182	Spain	27
United Kingdom	167	Taiwan	24
Japan	94	Iran	20
France	81	Sweden	20
Italy	71	Poland	19
Canada	65	Turkey	18
Australia	53	Greece	15
India	42	Norway	14
Netherlands	40	Russian Federation	14
Belgium	36	Hong Kong	13
South Korea	34	Israel	13

2.4. Analysis based on the various subject Area

A pie chart shown in figure 3. gives a clear idea about the research going on in the area of image processing using LBM for CFD applications. Since the topic is quite interdisciplinary in nature the maximum publications have been made in the field of engineering which is about 35 %. Considerable amount of work has also been done in the field of computer science (18%). As work on the current topic is of utmost use and importance in the field of medical and could be of much use to the clinicians in the diagnosis of the several diseases in the initial stages there has been about 13% of work done in the medical field as well. Work done in the other significant areas include Physics and Astronomy (10%), Chemical Engineering (8%) and Mathematics (8%).
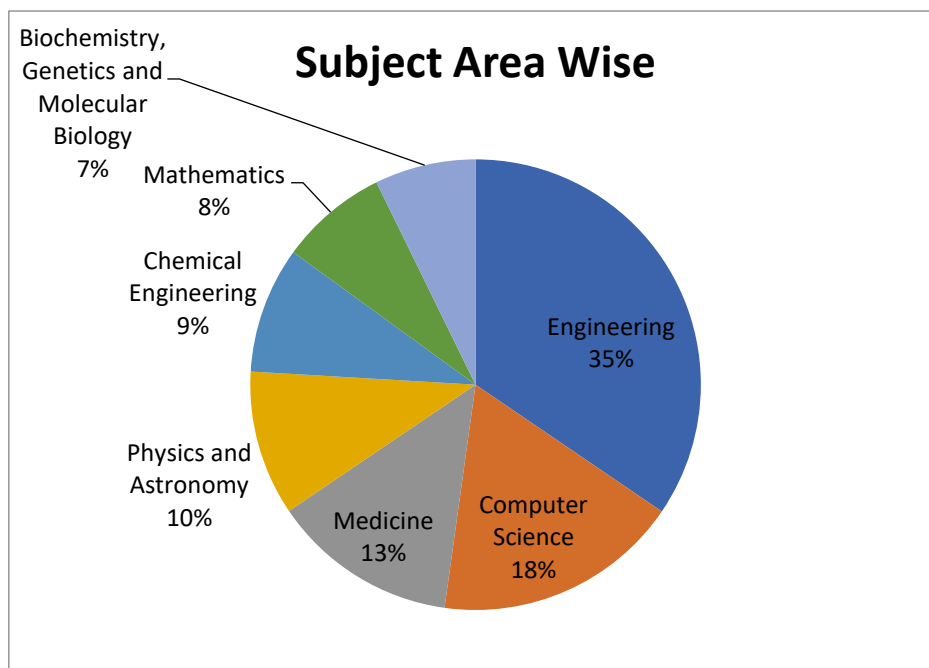
Figure 3: Top seven subject areas in Image processing using LBM
Source: https://www.scopus.com/ (accessed on January 19, 2021)

2.5. Document type-wise publication trend analysis:

Document type wise list of documents that has been published in the areas of image processing using LBM has been shown in table 4. From the various document types the maximum number of publications has been Articles. Conference papers and review papers also have been substantial amount of publications but lesser than that of article publications.

Table 4: Document type-wise number of publications
Source: https://www.scopus.com/ (accessed on January13, 2021)

Document Type	Publications	Document Type	Publications
Article	1019	Editorial	5
Conference Paper	585	Short Survey	4
Review	46	Note	3
Conference Review	43	Book	1
Book Chapter	19		

By drawing a pie chart we find a clear picture regarding the publication in various document types. The chart in Figure 4 shows that maximum contribution is done in Articles followed by Conference papers and review papers. Others in the pi-chart includes editorial ,short survey, Note and book, where the publications are not that significant.
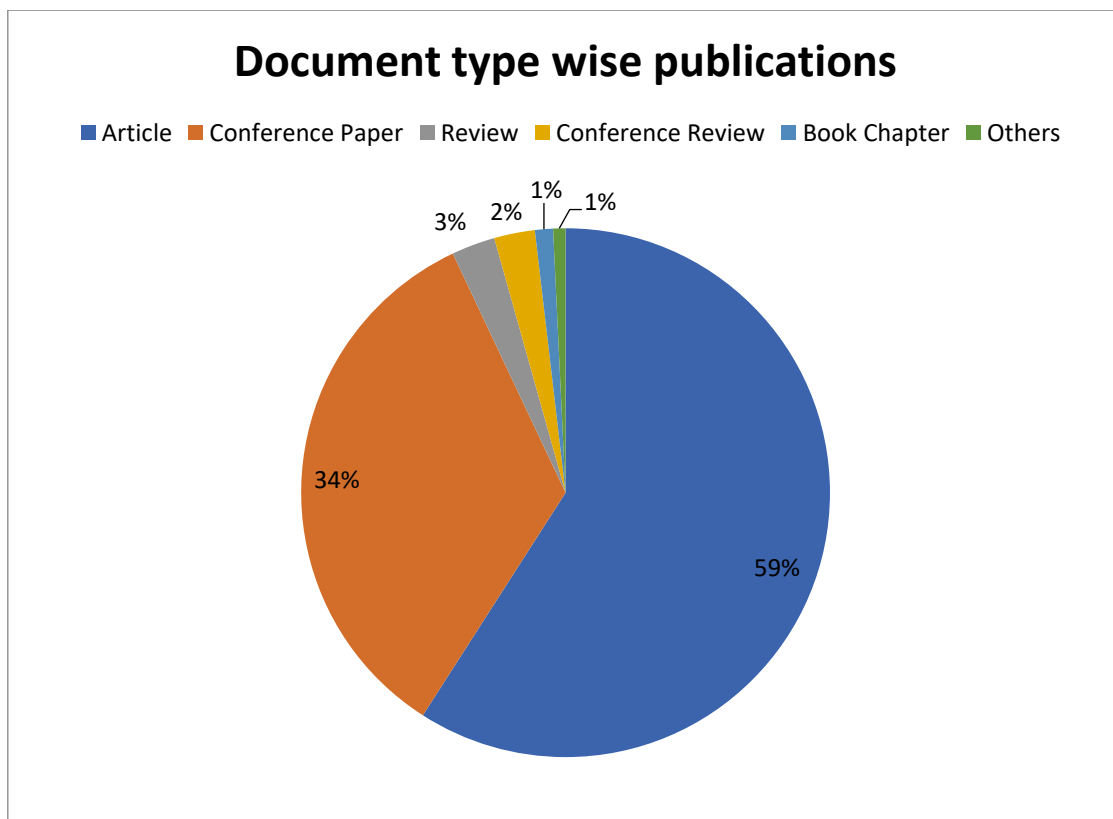

Figure 4: Document type-wise publications trend
Source: https://www.scopus.com/ (accessed on January 19, 2021)

2.6. Authors based analysis:

A bar graph representation of shown in figure 5 shows the most 10 relevant authors who have contributed significantly in this field. We see that Steinman, D.A(14). and Xu, X.Y hold the maximum number of publications in this area followed by researchers like Cebral, J.R(12) and Chen, Y(12) who have also contributed significantly in this area. Being an interdisciplinary area of research we can find many researcher working on this particular area. Other researchers include Segers, P(11)., Hughes A.D(9), Yoganathan, A.P(9)., Frangi A.F(8), Long, Q.(7), Antiga, L (6) who have given their valuable contribution
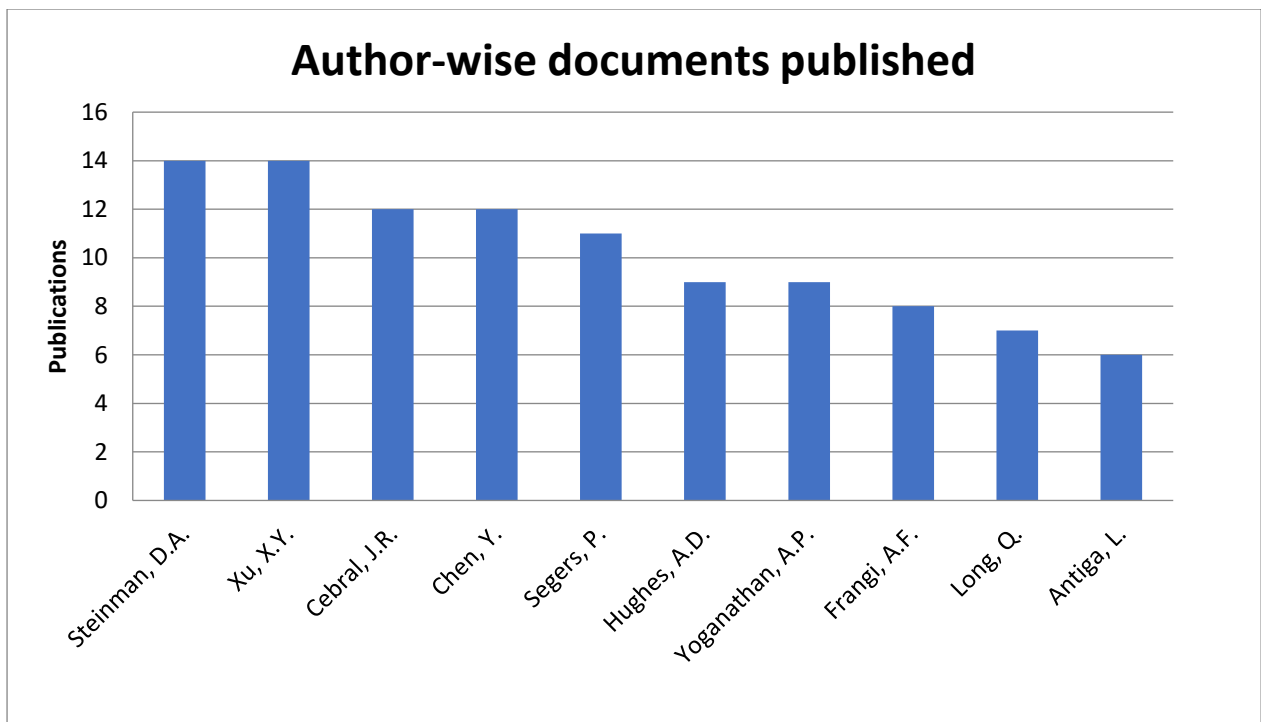

Figure 5: The author wise publications trend
Source: https://www.scopus.com/ (accessed on January 19, 2021)

2.7. Affiliation Institutes based analysis:

The graph shown in in figure 6 clearly shows the top 10 research centres or universities highly engrossed in researched in this particular area. Among the several institutions we see that Imperical college in London have the maximum number of publications in this area having 36 publications. CNRS Centre National de la Recherche Scientifique and Georgia Institute of Technology have 26 publications. Other major institutes include Politecnico di

Milano(19) and Universiteit Gent (18) . Emory University, Stanford University, University of Toronto and National University of Singapore have 16 affiliations each.
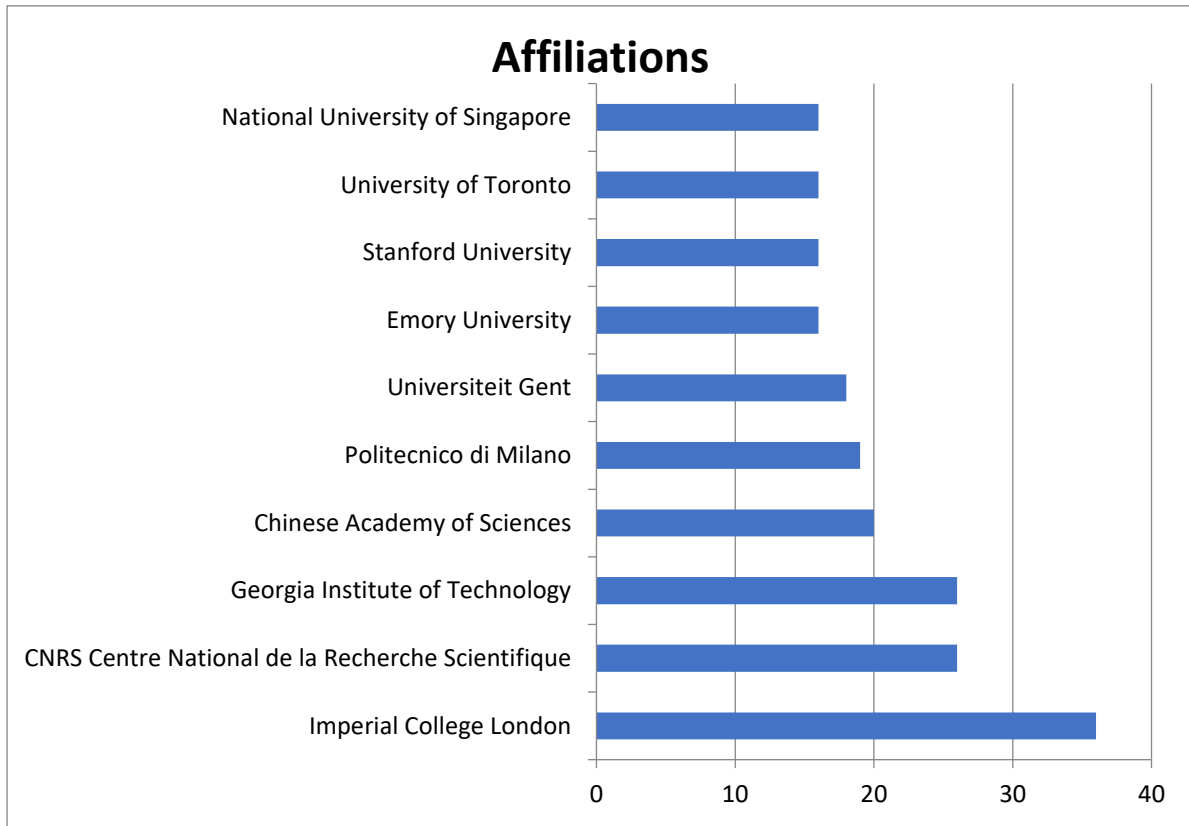

Figure 6: Top 10 Affiliation-wise institutes or research centres
Source: https://www.scopus.com/ (accessed on January 19, 2021)

2.8. Funding Sponsors based analysis

Being an important topic of investigation, many research institutions have funded to aid and help researchers to work more on this field. To top the list "National Natural Science Foundation of China have contributed the maximum for 73 researchers. Other major contributors include National Science Foundation(43), National Institute of Health (35) , Engineering and Physical Sciences Research Council (22). Therefore statistics gives a clear picture of the importance of the area of research. More number of sponsors shows that many reasearchers are willing to work and many funding organizations find it an essential research
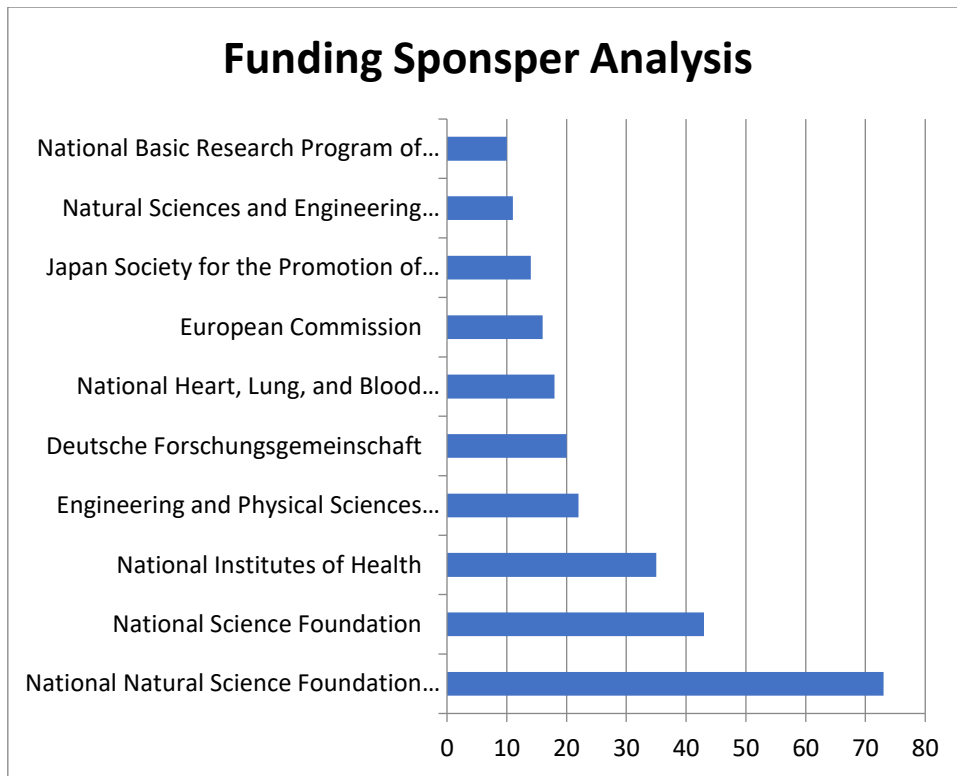
Figure 7: Top Ten funding sponsors
Source: https://www.scopus.com/ (accessed on January 19, 2021)

2.9. Language Based Analysis

While surveying about the various languages in which the papers have been published we see that maximum papers have been published in English as being a global language. Apart from English a few amount of paper has been published in Chinese too. Publications in languages like German , Japanese , French, Turkish, Polish , Russian and Spanish have also been seen but the amount of published papers are quite negligible and hence been categorized as others in the pie chart shown in figure 8.From this analysis we see that English being a global language has maximum publication in this language, but China has also been working considerably to leave a mark in the global scenario and thereby yielding to 3 percent of the total publications, where all other languages have hardly 1 percent of the total publications of papers.
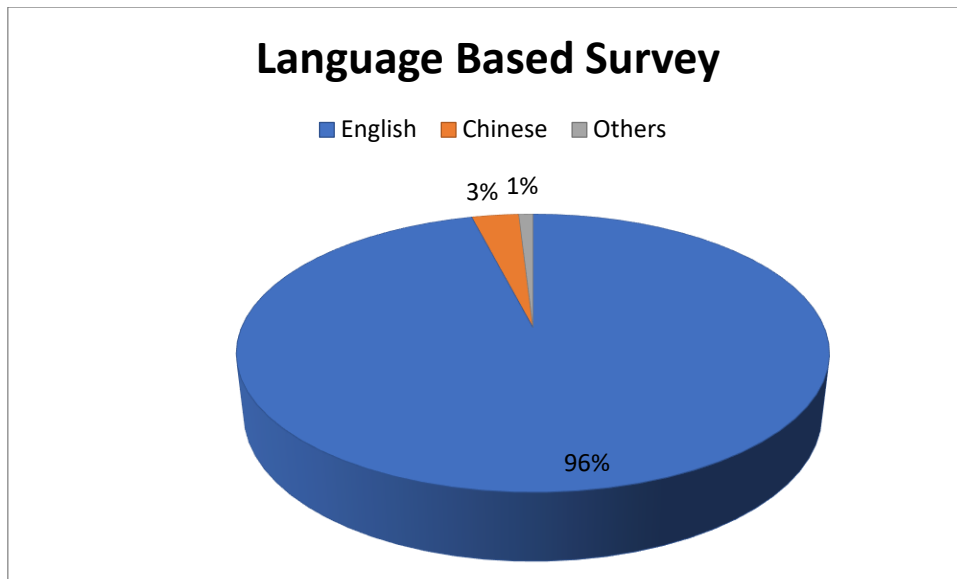
Figure 8: Language wise trend analysis
Source: https://www.scopus.com/ (accessed on January 19, 2021)

2.10. Source title based trend analysis:

The graph given in the figure clearly shows the analysis of the various journals published in this field . We could see that journals from various fields have been published. From the various journals maximum publications have been done in Proceedings Of SPIE The International Society For Optical Engineering(39) followed by SAE Technical Papers (27) , Ifmbe Proceedings (24) and Chemical Engineering Science (17). Journals like Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics (16), American Society Of Mechanical Engineers Fluids Engineering Division Publication Fedsm (15), Experiments In Fluids etc have also many documents published in the current topic. Publications in varied journals shows the importance of this interdisciplinary topic in the society and the urge to work on it by different researchers across different field.
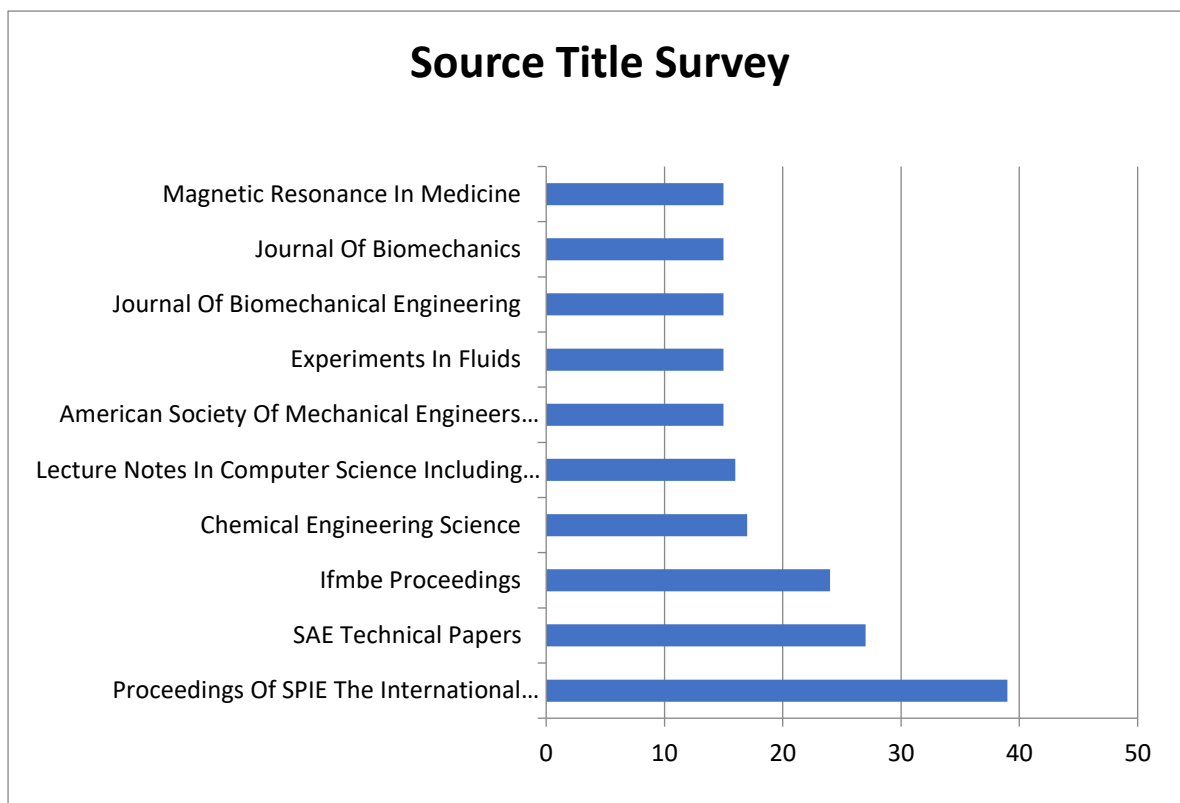
Figure 9: Analysis based on Source title.
Source: https://www.scopus.com/ (accessed on January 19, 2021)

2.11 Citations based analysis:

More number of citation implies the importance of a publication and they influence they give in the field of research. Increase in citations implies the increase in the appreciation and value of the work. Figure 10 shows the citation analysis of the topic for the past 5 years. From the graph taken from the Scopus Database we see an increasing trend in the citations. The graph shows that the citations have been constantly increasing from 2015 to 2020 showing that valuable amount of research is on-going in this field. The h- index is 68 which implies that out of 1726 documents 68 documents have been cited 68 times

Figure 10: Last five years of citations.
Source: https://www.scopus.com/ (accessed on January 19, 2021)

Figure 11: h- index for documents
Source: https://www.scopus.com/ (accessed on January 19, 2021)

Table 5 shows the highest ten documents in the related field from the data collected from the Scopus database.

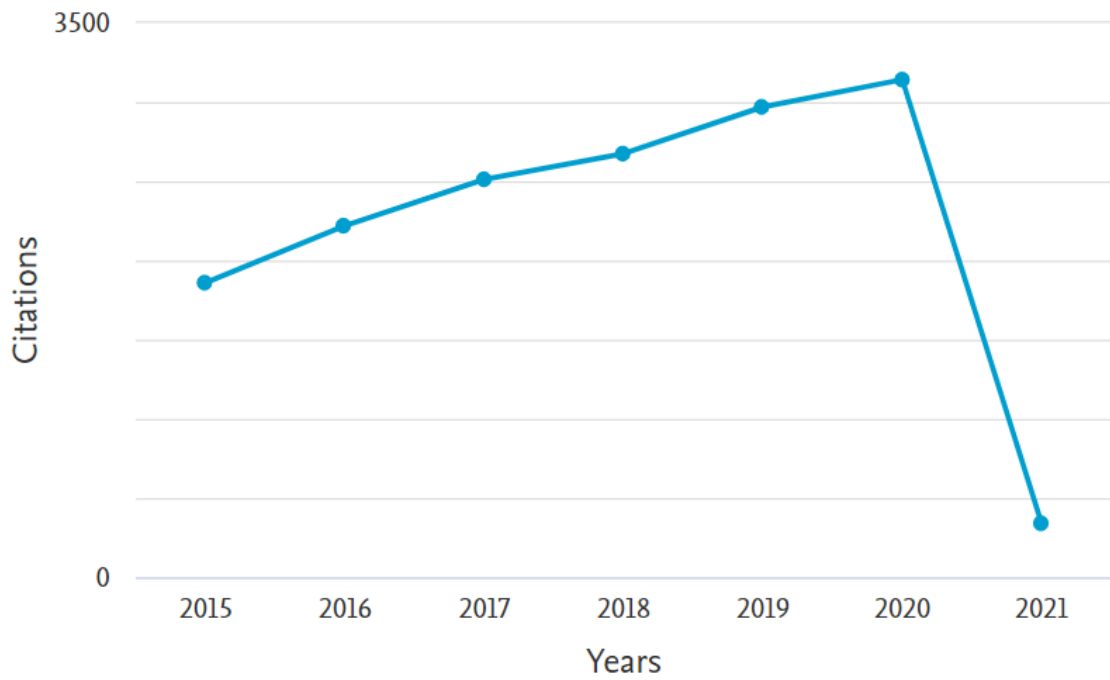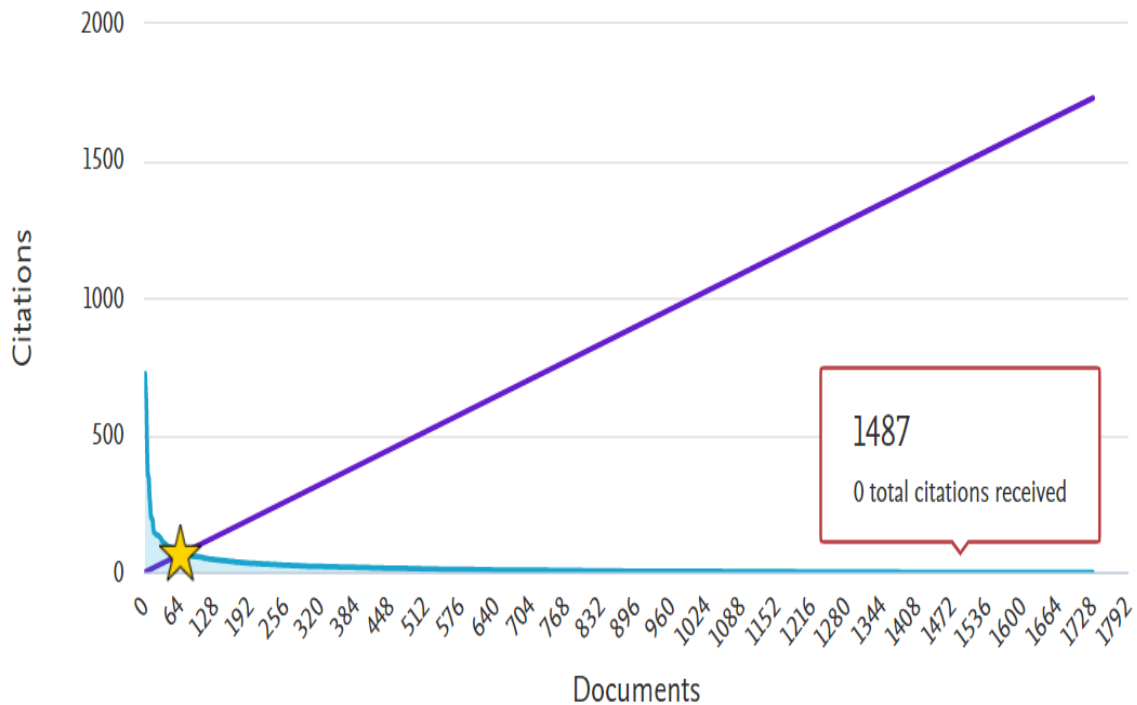| S. No	Publication Year	Authors	ISSN	Journal Title	2017	2018	2019	2020	2021	subtotal
1	2011	Koo B.-K., Erglis A., Doh J.-H., Daniels D.V., Jegere S., Kim H.-S., Dunning A., Defrance T., Lansky A., Leipsic J., Min J.K.	7351097	Journal of the American College of Cardiology	91	75	79	82	4	331
2	2009	(Henriques et al., 2016)	457825	Computer Methods in Applied Mechanics and Engineering	70	76	84	67	17	314
3	2012	Markl M., Frydrychowicz A., Kozerke S., Hope M., Wieben O.	10531807	Journal of Magnetic Resonance Imaging	53	38	52	74	6	223
4	2008	(Faggiano et al., 2013).,	1400118	Medical and Biological Engineering and Computing	50	59	45	48	2	204
5	2001	(Ebrahimi et al., 2013).	10636919	Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition	43	44	49	35	6	177
6	2016	(Gosling et al., 2019)., Narracott A., Von Tengg-Kobligk H., Soto D.A.S., Hsiao S., Lungu A., Evans P., Bressloff N.W., Lawford P.V., Rodney Hose D., Gunn J.P.	13556037	Heart	23	15	46	38	4	126
7	2009	Castillo R., Castillo E., Guerra R., Johnson V.E., McPhail T., Garg A.K., Guerrero T.	319155	Physics in Medicine and Biology	40	41	25	19	0	125

8	2005	Cebral J.R., Castro M.A., Burgess J.E., Pergolizzi R.S., Sheridan M.J., Putman C.M.	1956108	American Journal of Neuroradiology	27	39	28	22	1	117
9	2013	Charonko J.J., Vlachos P.P.	9570233	Measurement Science and Technology	26	23	19	22	2	92
10	2009	Piccinelli M., Veneziani A., Steinman D.A., Remuzzi A., Antiga L.	2780062	IEEE Transactions on Medical Imaging	23	12	19	25	1	80

3.Network Analysis

Network Analysis can be beautifully portrayed using various software available to give a clear picture of the various attributes. We have used VOSviewer software for network analysis using Scopus data. By taking two attributes for comparison the relationship between any two attributes can be studied. The network analysis between source titles and index keywords based on co-occurrence has been studied and represented in figure no.12. The extent of occurrence is indicated by the size of the graph. The distance between the keywords shown in the graph indicates the closeness of relationship between them. Computational Fluid Dynamics has a very strong impact with other keywords. The ones with the same colour keywords indicated the related clusters formed by these keywords. By selecting the minimum number of occurrence of keywords to be 5 , we could find that 1281 keywords could meet the threshold.
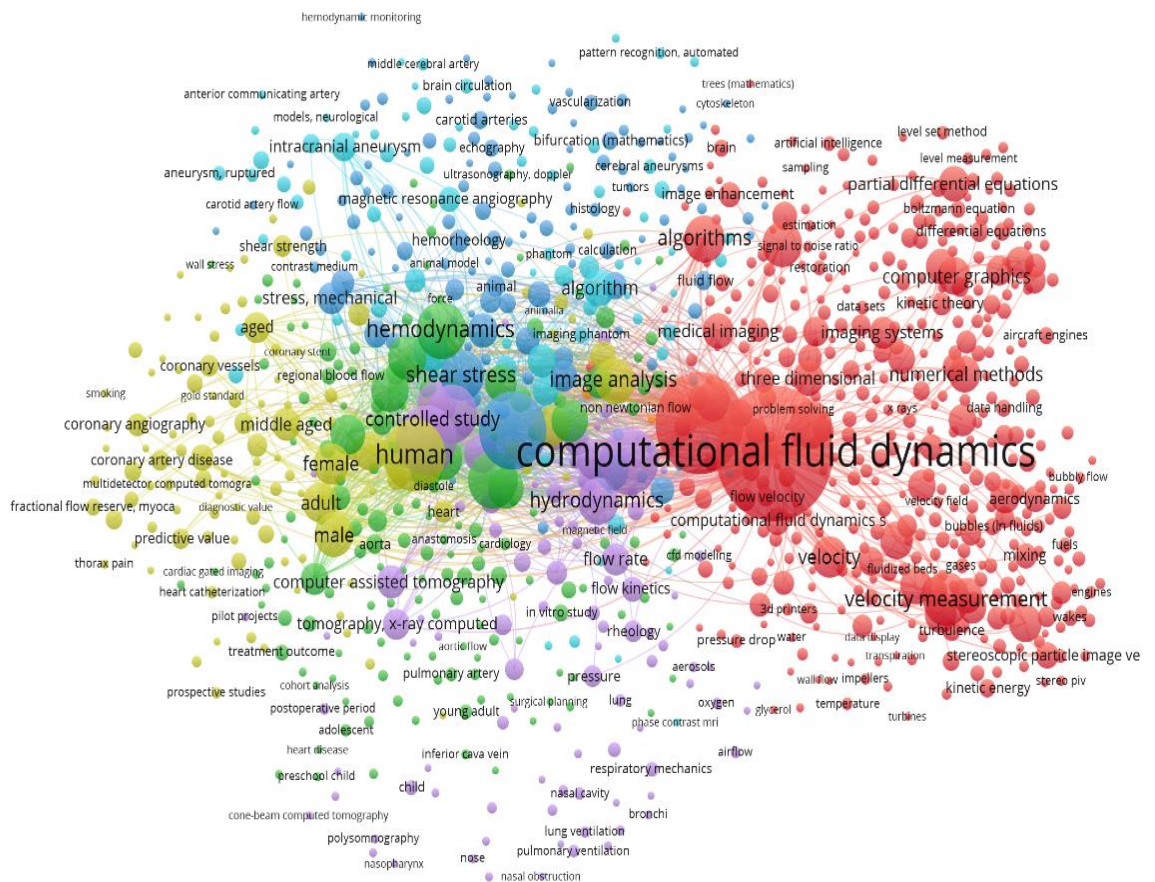

Figure 12: Network Analysis diagram based on keywords and source title.
Source: https://www.scopus.com/ (accessed on January 19, 2021)

Figure 12 represents the collaboration between the authors and co-authors. The links in the graph shows the collaboration among various authors. Only 86 authors met a threshold of minimum 5 documents published by them. We see that many authors have collaborated though there are many independent contributors too. Being a multi-disciplinary topic we can see some authors from various domains working on it independently.

Network Analysis diagram based on Authors collaboration.
Source: https://www.scopus.com/ (accessed on January 19, 2021)

4. Future work

A generic bibliometric survey has been done using Scopus database. With increase in the number of research in this inter-discipinary field we could find that the analysis is subjected to change and could be utilised and be of use for fresh researchers who would like to work upon this novel topic. We have used only Scopus database in this paper. Apart from Scopus there are other databases like Web of Science, ScienceDirect, Google Scholar etc. which would help us to compare and help us understand better. We have covered many parameters of comparison , but several other parameters could also be compared and analyzed. We have

included softwares like Gephi and vosviewer, but there are various other softwares available to analyse and compare various data so that our understanding about the research going on a particular field of research would be clear. Using various parameters and combinations could always be a scope to analyse one's search.

5.Conclusion

This bibliometric survey on Image Processing techniques using Lattice Boltzmann Method for CFD simulations gives us an insight of the amount of research work going on the particular area. Being it an inter-disciplinary study we see that the amount of research is not flooded and if we refine our research and focus on exactly on the topic , we see that only five documents have been found. Hence the need to work on the current topic becomes inevitable thereby showing the need for research. From the geographical analysis we see that USA and China have been actively contributing in the particular research. By this bibliometric survey we see that a particular subject or topic could be researched not only from from engineering domain but also from various other domains like Computer Science , medicine, physics, biochemistry etc. Maximum article publications (59%) also reveal that proper research is going on in this topic. The author survey helps us in knowing the major contributers who contribute to our areas of interest and the quality of work could be analyzed through citations and h index. Like we see that the major contributors include Steinman, D.A., Xu, X.Y., Cebral, J.R., (Yu Chen et al., 2020) (Steinman & Pereira, 2019)and one could refer their specific papers to know more about the topic. Using colorful images and graphs a clear understanding between various parameters could be analyzed.

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