Vibration Analysis in Industry 4.0: Machine Learning, Energy Harvesting, and Bibliometric Analysis

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To Cite this Article

Arshad Mehmood, "**Vibration Analysis in Industry 4.0: Machine Learning, Energy Harvesting, and Bibliometric Analysis**" Journal of Science and Technology, Vol. 08, Issue 05,-May 2023, pp01-21

Article Info

Received: 10-05-2023 Revised: 12-05-2023 Accepted: 15-05-2023 Published: 22-05-2023

Abstract: This research investigates the significance of bibliometric analysis, energy harvesting, and machine learning and diagnostic techniques to machine vibration analysis within the context of Industry 4.0. The study highlights the importance of early detection of machine defects and issues in reducing the likelihood of downtime and costly repairs and ensuring the optimal performance of industrial operations. Energy harvesting systems, machine learning, and diagnostic procedures are only some of the technologies used in the research of machine vibration analysis. Using these methods, it has been demonstrated that vibration patterns in machines can be analyses and predicted, that mechanical vibration energy can be converted into electrical energy, and that energy costs can be lowered. The study also includes a bibliometric analysis of the literature based on VOSviewer. Linear vibration, non-linear vibration, and vibration analysis are some of the topics it explores as it surveys the literature on vibration analysis of machines. Future research directions are proposed, and new perspectives on the current status of the field's study are provided. Practical implications for academics, professionals, and decision-makers in engineering and technology domains are derived from the study's findings, which call attention to the necessity for further study and improvement of machine vibration monitoring in Industry 4.0. This research contributes to the existing literature by providing valuable insight into the potential impacts of energy harvesting, machine learning, and bibliometric analysis on business processes.

Keywords: Linear Vibration, Industry 4.0, nonlinear vibration, Vibration analysis for machine monitoring and diagnosis, Energy harvesting

1 Introduction:

Broadband tri-stable energy harvester uses piezoelectric components and a magnetic field-induced triple-well potential to boost energy harvesting capability. The dynamic features and enhanced responsiveness over bi-stable systems [1] have been verified by both theoretical modelling and experimental study. Nonlinear dynamic features under low-frequency activation of magnetically connected piezoelectric energy harvesters with changing external magnetic field angles were investigated. For electromechanical interactions, it produces a nonlinear dynamic equation. [2]. Bi-stable energy harvesters, when activated by low-frequency base movements, generate vibrations consisting of both stationary rapid and slow components. Nonlinear potential barriers boost collected power by transforming slow oscillations into rapid ones, and the slow-fast response decomposition [3] makes this process more transparent. We suggest four different case studies that make use of the nonlinearity of geometric stiffness in structural design to provide benefits in a variety of contexts, such as achieving high-static stiffness while maintaining low dynamic stiffness [4]. In order to overcome the difficulties that linear resonant systems have in catching low-frequency vibrations [5], nonlinear energy harvesting devices built at the elastic stability limit perform better in coloured noise settings. Energy harvesting devices that rely on linear vibration can only work within a narrow frequency range. Expanding the resonant response and enhancing energy collection [6] are two ways in which performance may be enhanced in essentially nonlinear systems with a large nonlinear connection. This hypothesis for bi-stable vibration isolators (BVIs) emphasises the bi-stable vibration isolation process. The use of bi-stable structures for vibration isolation is on the rise, and they are already widely used in vibrational energy harvesting. The isolation mechanism may be determined by calculating the nonlinear restoring force and potential energy [7]. The use of piezoelectric buckled beams for the collection of energy from random vibrations is explored. In its buckled state, the axially loaded beam shows increased power production throughout a broad resistive load range, with increases of up to tenfold compared to the unbuckled condition. The idea has promise for converting mechanical energy into electrical power in situations where there are vibrations in the environment [8]. Using generalised harmonic transformation and similar non-linearization techniques, we developed a semi-analytical solution for the random response in nonlinear vibration energy harvesters when stimulated by Gaussian white noise. Power production and mean-square response may thus be more easily assessed [9]. Nonlinear vibration energy harvesting systems subjected to exponentially correlated Gaussian coloured noise have had their probabilistic responses studied using a quasi-conservative stochastic averaging technique [1]. The method utilises a transformation and residual phase combination to study the workings of the nonlinear vibration electromechanical coupling system and improve the efficiency of energy harvesting. [10]. For energy harvesting systems that are nonlinear and are sensitive to Gaussian white noise [1], a stochastic averaging technique has been devised. The influence of the external circuit on the mechanical system is modelled as quasi-linear stiffness and damping components in the generalised harmonic transformation. Improve energy harvesting performance by analysing mean-square electric voltage and mean output power with this method [11]. Broadband energy harvesting for weak excitations has been proposed using nonlinear tristable harvesters [1]. High-energy voltage output requires large-amplitude oscillations because the harvesters are extremely sensitive to ambient vibrations. An investigation on the enhancement of nonlinear tristable energy harvesters [2] uses harmonic balance analysis. Using the Jacobian matrix and the harmonic balancing approach, they gave theoretical explanations and stability analyses. The study also looked at how sensitive dynamic characteristics were to changes in system parameters, uncovering that performance may be greatly improved by numerical simulations [7]. Finally, the harmonic balance analysis of nonlinear tristable energy harvesters is a valuable technique for developing and evaluating these systems [12] because it provides helpful information for enhancing energy harvesting performance in low-level excitations. The magnetic circuit travels in relation to the ME transducer when the harvester is triggered, creating a magnetic field and electrical energy [5]. Wireless sensors and other low-power devices may be able to run on this technology [13]. Energy harvesting potential is demonstrated by presenting and validating a topology modification strategy for adjusting nonlinear vibration of planar springs [14]. Broadband and frequency-doubling capabilities are provided by revolving pendulums in a magnetoelectric vibration energy harvester. The 970.2 W load power is the result of an analysis of the model's nonlinear vibration, frequency, and electrical output [15]. A new 2D broadband vibration energy harvester concept uses a magnetoelectric (ME) transducer that can operate across a broad range of vibration frequencies and in two dimensions. The cantilever rod with a circular cross-section gathers energy from environmental vibrations via nonlinear magnetic force behaviour, expanding the frequency bandwidth [16]. The magnetoelectric generator uses the vibrations created by magnetic levitation to produce electricity. To improve power output and frequency response, it makes use of magnetostrictive material, which has a high energy density and a robust magneto-mechanical coupling effect [2]. The harvester is able to produce high voltage and power at low frequencies thanks to this [5]. The generator's potential for collecting vibration energy is demonstrated by its high current density, low impedance, waterproofness, and scalability [17]. This study presents a vibro-impact oscillator with three degrees of freedom as the basis for a triboelectric energy harvester [1]. We develop dynamic and theoretical models for the harvester's oscillator. The impacts of nonlinear dynamical response on performance [18] are investigated by analysing the dynamic response and electrical output for different mass ratios and mass spacings. A device with a 460% boost in bandwidth below 80Hz [19] demonstrates how this technique enhances energy harvesting from low-frequency sources while simultaneously improving bandwidth. Nonlinear Energy Sink (NES) prototypes are being built and tested in conjunction with electromagnetic energy harvesters [2]. The NES is a passive vibration absorber that is nonlinearly connected, allowing it to take in energy across a broad spectrum of frequencies [1]. While NES is more efficient than regular Tuned Mass Dampers (TMD) and has no natural frequency of its own, it is nonetheless vulnerable to small changes in design parameters or starting conditions [20]. Using piezoelectric energy harvesters, researchers have analysed and optimised the factors that affect the dynamic response of linear and nonlinear vibration absorbers. The optimisation strategy makes use of a genetic algorithm and response surface approach [21] to enhance the functionality of the absorber and the energy harvester. Increased efficiency may be achieved via the use of nonlinear vibration energy harvesting and suppression technologies by expanding the frequency bandwidth and output power while reducing the transmission rate and transfer energy. Constraints in the structure, noise that isn't sinusoidal, and a lack of progress in the field all pose problems. Improving performance is dependent on a number of elements, including implementation, configuration, and an efficient design. Capturing energy from vibrations and using it to power sensors is essential [22]. Search engine results suggest that energy from weak (3 m/s2) and infrequent (20 Hz) environmental vibrations can be salvaged using a nonlinear multi-stable piezomagnetoelastic harvester array. Nonlinear piezomagnetoelastic harvesters are proposed for use in the proposed harvester array, with one kind featuring a tri-stable configuration and the other a mono-stable one. The proposed array is sensitive to wideband vibrations of low intensity and low frequency [5-8]. The proposed harvester array can effectively absorb energy from low-amplitude vibrations despite its compact size. Applications where low-intensity and low-frequency vibrations are present, such as those encountered in the automotive and aerospace industries, might benefit from the suggested harvester array [23]. A web search for a piezoelectric vibration energy harvester with variable frequency and bandwidth utilising several nonlinear techniques does not yield precise results. However, work has been done on nonlinear piezoelectric vibration energy harvesters, such as the proposed compact nonlinear multi-stable piezomagnetoelastic energy harvester array [9], that can generate power from low-frequency and low-intensity vibrations. One tri-stable and one mono-stable nonlinear piezomagnetoelastic harvester type are proposed for the harvester array [24]. The proposed harvester array can effectively absorb energy from low-amplitude vibrations despite its compact size. No research were found in the search results [25], [26] although it is possible that these energy harvesters can be programmed for frequency and bandwidth using other methods.

2 Bibliometric Data and Method

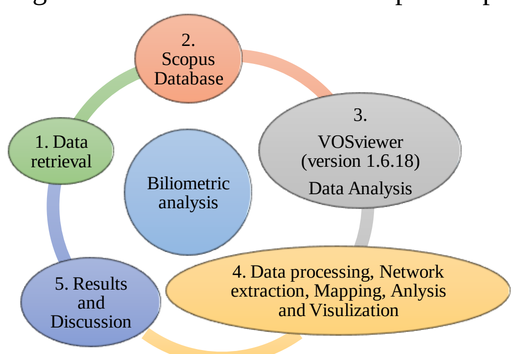
A bibliometric analysis is the process of analysing scientific documents and literary data on a large scale in order to determine facts about a specific study field or issue. This entails gathering, organising, and analysing data from scientific publications in order to detect trends, patterns, and linkages among various study topics, authors, institutions, and nations [27]. The study obtained and analysed published papers from Scopus over a 14-year period using bibliographic mapping. This mapping technique entailed analysing publications in order to uncover patterns and linkages among various study fields, authors, organisations, and nations. The researchers gained a better understanding of the present state of knowledge, research trends, and emerging ideas in a certain study field or topic by analysing the papers. Through this approach, the researchers were able to identify study gaps and opportunities for further exploration. Scopus, an extensive database of scientific publications, gave the researchers access to a wide range of peer-reviewed journals, conference proceedings, and other scholarly material [28].

The extracted findings were saved in a comma-separated value format (.csv) file that matched the format of the gathered article. The file contained both the complete records of the extracted articles as well as their cited references. Figure 1 depicts a flowchart of the bibliometric analysis and methodological procedure. TITLE-ABS-KEY ("Linear vibration" AND "Industry 4.0" OR "Vibration analysis for machine monitoring and diagnostics" AND "Energy harvesting") is used for each item selected, and only articles based on keywords found in the Scopus database are used. As a consequence, 236 articles were discovered, and filters were used to extract relevant papers for data collection and evaluation using appropriate bibliometric factors [29].

3. Results and discussion

3.1 Annual trends of scientific publications

Figure 2 displays that 37.3% of all articles are in the discipline of engineering, physics, and astronomy, whereas 19.1% are in the subject of biology. The areas of material science and computer science also made substantial contributions. Figure 3 provides a concise overview of the total number of papers published to date and the amount of documents issued in each year between 2009 and 2023. The numbers show that the annual publication rate is rising, with a total of 223 papers expected to be released by the year 2023. Both 2018 and 2017 had 27 new papers published, but 2009 and 2010 saw only two new documents published each. The total number of papers published up to a specific year is known as the cumulative number of documents, and it has been steadily increasing throughout time. Increased study and development in the topics covered by these books is indicative of a long-term interest in the discipline. The information provides a snapshot of the field's development during the time span studied, revealing both broad trends and more specific patterns in the volume of literature generated.



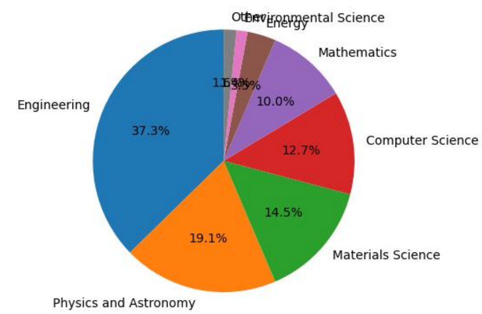


Fig. 1 Steps involved in data assessment and bibliometric analysis

Fig. 2 Subject areas

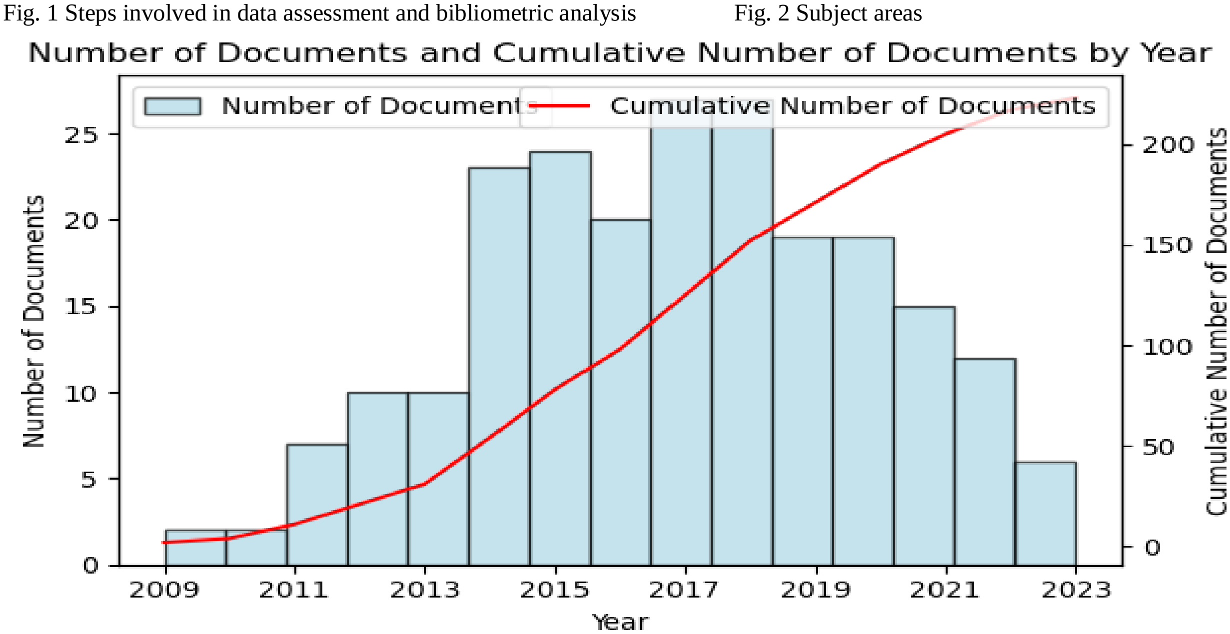


Fig. 3. Level of development of research on energy harvesting

3.2 Analysis of influential authors and Co-authorship mapping

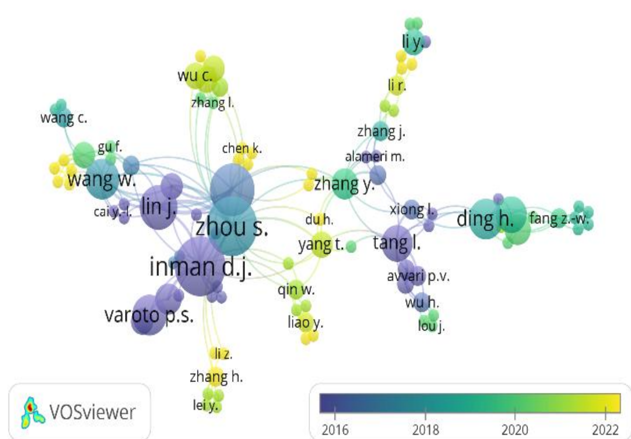
The number of citations received and the number of citations given are indicators of the importance of writers and their pioneering research in a certain academic field [30]. The authors hail from

Journal of Science and Technology
ISSN: 2456-5660 Volume 8, Issue 05 (May -2023)
www.jst.org.in *DOI:https://doi.org/10.46243/jst.2023.v8.i05.pp33 - 47*

a wide range of institutions throughout the world, including China's State Key Laboratory for Manufacturing Systems Engineering as well as those in Japan, Poland, and the United States. Inman D.J. has the most publications (11) followed by Cao J. (9) and Dai X. (8) in terms of output. There were five publications by Chen L.-Q., six by Ding H., and seven by Lin J. Inman D.J. has the highest number of citations (807), followed by Cao J. (812) and Lin J. (756). The average number of citations per document for Lin J. is 108, followed by Cao J. (90.22) and Inman D.J. (73.36). The highest cumulative h-index scores, which measure the number of publications having at least h citations, belonged to scholars D.J. Inman and Chen L.-Q. While Litak G. and Lin J. have only 31 and 12, respectively, Erturk A. has a high h-index of 59. since a whole, the information in this table is rather helpful, since it sheds light on the impact and output of a number of influential authors across many different areas.

Table 1: Leading author of the topic

Author	Institution	Country	Document	Total citation	Average citation	Total h index
Cao j.	State key laboratory for manufacturing systems engineering	China	9	812	90.22	40
Chen l.-q.	Shanghai institute of applied mathematics and mechanics	China	5	170	34	44
Dai x.	The key laboratory for optoelectronic technology & systems	China	8	230	28.75	25
Ding h.	Shanghai institute of applied mathematics and mechanics	China	6	175	29.16	21
Erturk a.	Department of materials and human environmental sciences	Japan	5	112	22.4	59
Harne r.l.	Department of mechanical engineering	USA	6	99	16.5	30
Inman d.j.	Department of aerospace engineering	USA	11	807	73.36	66
Li p.	The key laboratory for optoelectronic technology & systems	China	8	234	29.25	9
Lin j.	State key laboratory for manufacturing systems engineering	China	7	756	108	12
Litak g.	Department of Automation, Lublin University of Technology	Poland	5	52	10.4	31



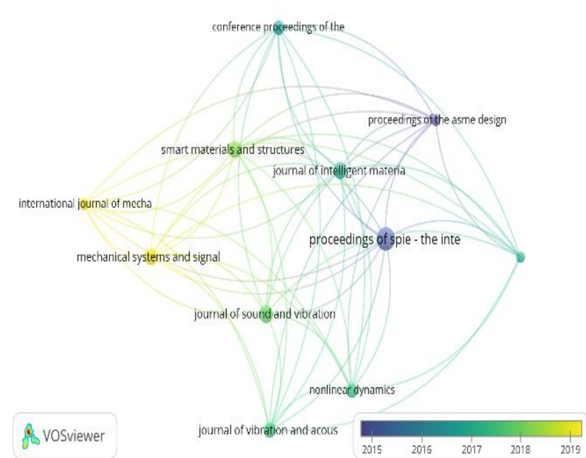


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Fig. 4. Overlay Visualization of Co-authorship analysis

Fig. 5. Network Visualization of publications by source

3.3 The network visualization of sources

The most credible authors will publish their findings with appropriate referencing. Scientists can quickly and readily determine which journals and databases are the most suitable for publishing their findings [31], [32]. For a variety of publications in the fields of mechanical engineering, materials science, and physics, the table below displays the number of documents, the number of citations, and the overall link strength. Most articles (22 total) may be found in Proceedings of SPIE - The International Society for Optical Engineering, followed by the Journal of Sound and Vibration (12 total) and Smart Materials and Structures (11 total). The Proceedings of the ASME Design Engineering Technical Conference is the least fruitful source, with only six documents. International Journal of Mechanical Sciences received the fewest citations (188), followed by Journal of Sound and Vibration (467), and then Smart Materials and Structures (666). A source's link strength is measured by the total number of links between articles in that source, with higher values indicating more connections between the works in that source. Journal of Sound and Vibration comes in second with 1309 total link strength, followed by Proceedings of SPIE - The International Society for Optical Engineering with 1421 total link strength. Insightful data regarding the output and impact of various major publication sources across a variety of fields are shown in this table. Journal of Sound and Vibration, Smart Materials and Structures, and Journal of Intelligent Material Systems and Structures are highlighted for their roles as hubs of highly cited and interrelated research. The data in the table may also be used to help experts zero in on the best places to find new research for their fields.

Table 2: List of main sources of during the period 2009–2023

Source	Publication	Citations	Citation per document	Total link strength (TLS)
conference proceedings of the society for experimental mechanics series	8	11		163
international journal of mechanical sciences	6	188		356
journal of intelligent material systems and structures	11	270		1346
journal of physics: conference series	5	15		121
journal of sound and vibration	12	467		1309
journal of vibration and acoustics, transactions of the asme	9	241		820
mechanical systems and signal processing	11	397		845
nonlinear dynamics	8	352		833
proceedings of spie - the international society for optical engineering	22	153		1421
proceedings of the asme design engineering technical conference	6	4		514
smart materials and structures	11	666		926

Journals in mechanical engineering, materials science, and physics are shown separately in Figure 5. The journals were grouped together based on their shared focus, readership, and perceived authority. The bulk (four out of five) of the entries in Cluster 1 are from a conference. Topics like stress analysis, vibration, and materials testing are discussed, all from the perspective of experimental mechanics. They provide a forum where experts in the area may share their findings with peers, and they are especially useful for spreading the word about cutting-edge methods for testing and assessing mechanical systems. There are three related elements in cluster 2 that include signal processing. The topics covered in these books vary from fault detection and condition monitoring to feature extraction and signal processing in mechanical systems. Academics and engineers in these domains rely heavily on them, especially when developing and improving methods for monitoring and diagnosing mechanical systems. There are three items in cluster 3 that deal with dynamics and related topics. Nonlinear dynamics, chaos theory, and vibration analysis are only some of the topics covered in these articles on the analysis and modelling of dynamical systems. Academics and engineers in these domains may greatly benefit from them, especially when it comes to developing and improving methods of understanding and forecasting the behaviour of mechanical systems. This paints a clear picture of the similarities and differences in the content, readership, and impact of academic articles in mechanical engineering, materials science, and physics.

3.4 Most influential publications

In this section, out of 248 documents, 36 met the requirement of having 50 citations for each document. The 10 most cited studies found in the Scopus database are mentioned in Table 3. Most researchers cite documents for academic work with more citations due to work being extremely high and suitable [33].

Table 3: Most influential publications

Rank	Total Citations	Title	Author	Journal	Ref
1	462	Broadband tristable energy harvester: Modeling and experiment verification	zhou s. (2014)	Applied Energy	
2	301	Piezoelectric buckled beams for random vibration energy harvesting	cottone f. (2012)	Smart Materials And Structure	
3	130	A Magnetoelectric Generator for Energy Harvesting From the Vibration of Magnetic Levitation	dai x. (2009)	IEEE Transactions On Magnetics	
4	121	A hybrid nonlinear vibration energy harvester	yang w. (2017a)	Mechanical Systems and Signal Processing	
5	115	Comparing Linear and Essentially Nonlinear Vibration-Based Energy Harvesting	quinn d.d. (2011)	Journal of Vibration and Accoustics	
6	114	Harmonic balance analysis of nonlinear tristable energy harvesters for performance enhancement	zhou s. (2016a)	Journal of Sound and Vibration	
7	102	A frequency and bandwidth tunable piezoelectric vibration energy harvester using multiple nonlinear techniques	wang x. (2017)	Applied Energy	
8	96	Internal resonance and low frequency vibration energy harvesting	yang w. (2017b)	Smart Materials and Structures	

9	93	High-efficiency compressive-mode energy harvester enhanced by a multi-stage force amplification mechanism	yang z. (2014)	Energy Conversion and Management	
10	91	A Vibration-Based Hybrid Energy Harvester for Wireless Sensor Systems	sang y. (2012)	IEEE Transactions On Magnetics	

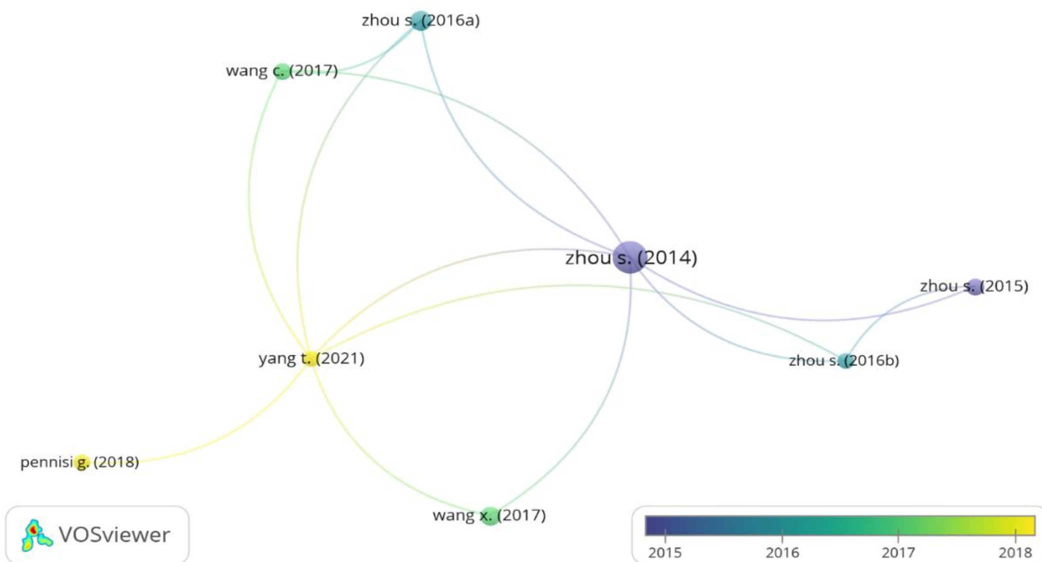

Fig. 6. The Network Visualization of documents based on citations

The paper "Broadband tristable energy harvester: Modelling and experiment verification" details the theoretical modelling and experimental examination of a piezoelectric-based vibration energy harvester with a triple-well potential powered by a magnetic field. Using Hamilton's principle and the energy technique, a mathematical model is constructed to characterise the response qualities of tristable nonlinear energy oscillators. It is shown that the suggested electromechanical model can reflect the dynamic features of broadband tristable energy harvesters using a combination of numerical simulations and tests conducted at excitation frequencies ranging from 1 to 20 Hz. Buckled piezoelectric beams have been studied for their possible use in collecting energy from random vibrations. published a paper titled "Piezoelectric buckled beams for random vibration energy harvesting" [1, 2, 4] after conducting study on the subject. In the study, a piezoelectric beam with a shaker-excited base is described as the energy harvesting system. There are two clamps; one is stationary, while the other may be moved along a micrometric stage. Numerous aspects of the piezoelectric buckled bridge model are examined as well. The authors argue that nonlinear vibration harvesters are preferable to resonant harvesters due to their greater versatility in the frequencies they can convert into usable energy [6]. This document is intended to be a resource for those studying the use of buckling beams in piezoelectric energy harvesting. A magnetoelectric generator for energy harvesting from the vibration of magnetic levitation is discussed in the publication "A Magnetoelectric Generator for Energy Harvesting from the Vibration of Magnetic Levitation" [1] by Yang Zhu, J. W. Zu, and L. Guo. High voltage and power may be generated at low frequencies [4] because to the magnetostrictive material's high energy density and strong magneto-mechanical coupling effect. The generator is capable of harvesting vibrational energy in three dimensions, and its output is improved by a magneto-electric array [5]. To further increase energy transfer via resonant inter-well oscillations and supply a wider bandwidth at low-frequency excitation levels, a magnetic levitation-based hybrid energy harvester with a tri-stable nonlinearity-enhanced mechanism is proposed in another study [7].

3.5 The density visualization of keywords Co-occurrence

TLS density is defined by the size of the text, the color of the backdrop of the keywords, and the density colour. The sequence goes from yellow to green to blue in a TLS pattern. Keyword distancing [34] shows how closely related the research themes are. Both author-provided keywords and those appearing in the title, abstract, or keywords were included in the co-occurrence analysis. In Criteria I, the 1567 terms are filtered down to those with at least three appearances in Fig. 7. In order to fulfil the second criterion, 447 keywords were generated, and 18 of them appeared five times or more in Fig. 8.
Several common threads emerge from the investigation. Concentration is placed on energy harvesting, with several related search terms such as "broadband energy harvesting," "energy conversion," "energy efficiency," "energy harvester," and "energy harvesting systems." Keywords like "piezoelectric," "piezoelectric energy harvesters," and "piezoelectric vibration" also appear on the chart, suggesting that this topic is of interest to the users. Words like "structural dynamics," "vibration analysis," "vibration control," and "vibration energy harvesting" are all part of the lexicon of vibration and structural dynamics. Also appearing often are the terms "nanocantilevers," "magnetism," "nonlinear vibrations," and "resonance," among others. According to Fig. 7, some of the least used terms include "excitation amplitudes," "governing equations of motion," and "vibration suppression," all of which may be good candidates for future research.

In Fig. 8 [35], we see the results of a bibliometric analysis done with the programme Vosviewer, which identifies the most common and impactful terms in a collection of scientific publications dealing with energy harvesting and nonlinear vibrations. Each keyword is represented by a bar, the length of which is proportional to the term's frequency of occurrence and overall link strength.
Using Vosviewer, a bibiometric analysis of the most significant phrases in scientific publications on energy harvesting and nonlinear vibrations was conducted. "energy harvesting" is the most significant and prominent term, appearing 89 times with a total link strength of 115; "nonlinear vibration" is a close second, appearing 83 times with a total link strength of 109. If the field intensity and frequency are both high, then the effect is also high.
The terms "energy harvesting" (which appears 89 times and has a total connection strength of 115) and "nonlinear vibration" (which appears 83 times and has a total link strength of 109) are the most often used and strongly linked terms. This indicates that these are the most popular search terms related to energy harvesting and storage. A bibliometric analysis was run on a collection of scientific papers discussing energy harvesting and nonlinear vibrations using Vosviewer software; the findings are displayed in the table below. In the table, you can see how often each term appears and how strong its overall links are, with more frequent appearances and stronger links indicating a greater influence in the field of nonlinear vibrations. The importance of the term "piezoelectric" to this subject is shown in the frequency with which it appears (23) and the relative strength of its links (36). Piezoelectric materials and technologies

are widely used for energy harvesting due to their ability to convert mechanical vibrations into electrical energy. There are 7 instances of the word "piezoelectric energy harvesting" with an overall link strength of 8, indicating that studies in this field are still being conducted. With 14 and 5 occurrences, respectively, and total link strengths of 6 and 14, "vibration energy harvesting" and "vibration energy harvester" are rather weak keywords. These search terms suggest that researchers are always trying to improve methods for harvesting energy from mechanical vibrations, but their efforts may have little bearing on other fields of study. Seven occurrences and a total link strength of 5 for the term "nonlinear energy harvesting" suggest that research is being done into nonlinear methods to enhance the efficiency of energy harvesting. Six times, and with a total link strength of 11, the term "internal resonance" appears, demonstrating the significance of this issue in energy harvesting and nonlinear vibrations. Seven occurrences of the word "bistable" with a total link strength of 12 indicate that studies of bistable structures for energy harvesting are currently being conducted. Bistable structures, which have two stable states, can be used to transform low-frequency mechanical vibrations into high-frequency vibrations, which can be more easily collected. Research into the potential of nonlinear oscillators for energy harvesting is ongoing, as evidenced by the occurrence of the term "duffing oscillator" six times with a total link strength of seven. One simple mathematical model with nonlinear behaviour that has applications in energy harvesting is the Duffing oscillator. Despite their relative frequency, the overall connection strength for the terms "magnetic levitation" and "magnetoelectric transducer" is quite weak. These search terms point to ongoing research into magnetic and magnetoelectric methods for energy harvesting, although it's possible that this study's influence will be little compared to others. Because of the significance of nonlinear techniques in the fields of energy harvesting and nonlinear vibrations, the terms "nonlinear vibrations" and "nonlinear" have high occurrence and total link strength values. With a total link strength of 109, the term "nonlinear vibrations" indicates a rapidly expanding area of research. Among the less often used entries in the table are "magnetic levitation," "vibration energy harvester," and "duffing oscillator." Since there appears to be very little study in these areas compared to others, they may point to potential avenues for future investigation.

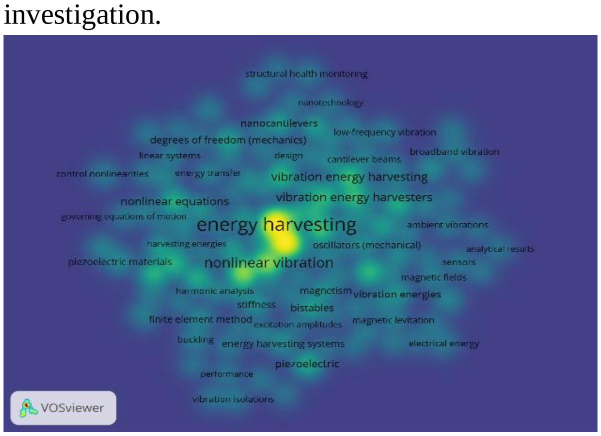

Fig. 7 Density visualization of keywords co-occurrence in the title, abstract co-occurrence in the title, abstract, and keyword list minimum 3 occurrences

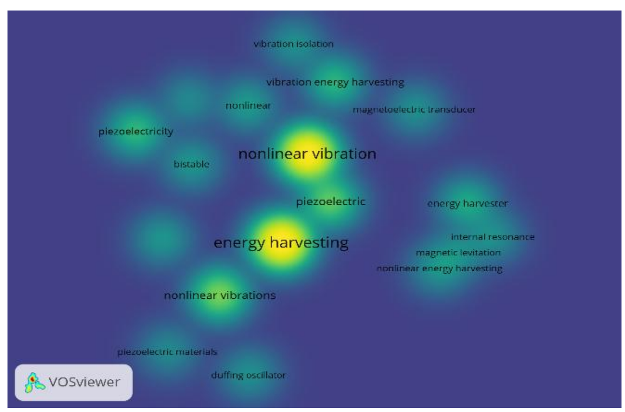

Fig. 8 Density visualization of keywords co-occurrence in the title, abstract co-occurrence in the title, abstract, and keyword list minimum 3 occurrences

Conclusion

The search engine results provided an in-depth analysis of the state of the art in nonlinear vibration energy harvesting. Several methods were tested for their viability in low-frequency and low-intensity vibration situations; they included tristable energy harvesters, nonlinear attachment systems, and magnetoelectric generators. Collecting, organising, and analysing data from scientific publications to reveal trends, patterns, and linkages in a certain study field or topic is known as bibliometric analysis. Scopus is a comprehensive database for doing bibliometric analysis since it gives access to a wide variety of peer-reviewed journals, conference proceedings, and academic literature. The significance of tracking the annual publishing rates of writers and their collaborators is stressed throughout the article. This study illuminates the research landscape and major actors in the energy harvesting area. Only 36 of 248 publications have at least 50 citations, however Table 3 shows the 10 most-cited research from Scopus. According to the results, "energy harvesting" and "nonlinear vibration" are the most relevant and influential terms in the sector, while "piezoelectric" is a promising area of study. Vibration, nanocantilevers, magnetism, and resonance are some more topics of research interest in addition to structural dynamics. Magnetic levitation, vibration energy harvester, and Duffing oscillator are three examples of less popular but potentially fruitful search terms.

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