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Analyzing Bibliometric Trends in the Social Internet of Things: A Review and Future Perspectives

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ABSTRACT

The study aims to fill the gap in the bibliometric analysis of the Social Internet of Things (SIoT) discourse, focusing on recurring patterns, exploring uncharted study domains, and proposing future directions in the developing interdisciplinary realm. The analysis used quantitative data from the Scopus database from 2012 to 2023, covering architecture, trust management, service composition, network navigability, and integration with upcoming technologies. The study revealed a 29.14% yearly expansion rate in SIoT research, demonstrating a dynamic and cooperative research environment. Keyword clusters included social interactions, multidisciplinary perspectives, network architecture, cybersecurity, trust administration, and social networking integration. The bibliometric study provides valuable insights for researchers, practitioners, and policymakers, enabling them to navigate the ever-changing Smart Internet of Things landscape and promote interdisciplinary collaboration for further advancements. Future studies should include qualitative assessments, examine societal implications, and explore future technologies within the Internet of Things (IoT) framework.

1. INTRODUCTION

The ubiquitous presence of interconnected devices, often known as the Internet of Things (IoT), has fundamentally altered how humans engage with technology. The boundaries between the physical and digital realms are becoming increasingly blurred, as demonstrated by the inclusion of intelligent sensors in our homes and health-tracking devices. Nevertheless, the progress of the future is not exclusively dependent on mere connectivity but rather on social interaction. Discover the evolving field of the Social Internet of Things (SIoT), where items go beyond their capabilities and form dynamic connections, mirroring the intricate networks found in human civilization [1].

SIoT refers to an advanced paradigm where objects equipped with sensing, communication, and processing capabilities are interconnected in a social-like network, similar to human social networks [1]. This concept extends the traditional IoT by enabling objects to autonomously establish social relationships based on their functionalities and interactions, mimicking how humans form friendships. These relationships can include ownership-based, co-location, and co-work connections [1-3]. SIoT aims to enhance IoT systems' scalability, discoverability, and interoperability, enabling more efficient data sharing, resource optimization, and personalized services. By leveraging social networking principles, SIoT can provide context-aware services and improve the overall user experience through intelligent, socially driven decision-making processes.

Researchers in the field of SIoT have endeavored to shed light on several aspects of this interdisciplinary domain, revealing its trends, problems, and future directions. Given the increasing integration of IoT with social sciences, researchers and practitioners must comprehend the bibliometric trends. Nevertheless, a significant research void exists in SIoT discourse, specifically regarding incorporating bibliometric analysis [2]. This research gap necessitates a targeted investigation into bibliometric trends in the IoT social aspect. This investigation aims to contribute to the ongoing discussion and influence the direction of future research in this field.

The scope of the study encompasses the exploration of the SIoT, focusing on how interconnected devices can form dynamic, social-like networks similar to human social networks. The study aims to enhance the understanding of SIoT's architecture, components, and integration with social networking and IoT technologies. Key objectives include improving IoT systems' scalability, discoverability, and interoperability, facilitating efficient data sharing, resource optimization, and personalized services. Additionally, the study seeks to fill research gaps through bibliometric analysis, particularly in service composition, discovery, network navigability, and trust management. The exploration extends to integrating SIoT with emerging technologies such as big data and cloud computing while addressing crucial issues like

trust, security, and ethical considerations in the evolving SIoT landscape.

The SIoT is a conceptual framework that integrates social networks with the IoT to establish a novel paradigm [3]; its objectives are to establish a representation of social networks by establishing connections between individuals and objects to enhance usability, scalability, and productivity inside businesses [4]. By increasing the accessibility and movement of items, it facilitates the advancement of smart cities, intelligent transportation, and other domains [5]. Integrating social interactions, user-generated information, and social context into the IoT ecosystem advances standard IoT systems, resulting in SIoT. It facilitates the exchange of information, cooperation, and collective decision-making among IoT devices [3].

Gaining insights into research trends in SIoT enables researchers and practitioners to remain abreast of the most recent advancements and improvements. It enables them to recognize new technologies, approaches, and issues in SIoT, which might inform future research paths [6]. Researchers can enhance the knowledge base by identifying and resolving gaps in the existing literature through a comprehensive awareness of research trends. Additionally, it aids in the identification of potential collaborations and partnerships with other scholars in related fields [3]. The literature review examines and evaluates the current body of research within a particular discipline. Its objective is to ascertain the present state of knowledge, identify research deficiencies, and outline prospective research avenues.

The fundamental elements of SIoT research entail establishing a robust theoretical basis. Essential works establish the foundation by clearly defining the concept, emphasizing its unique features, and distinguishing it from the wider IoT field [1, 3, 7]. Moreover, it is essential to comprehend the practical implementation of Social Network Analysis (SNA). The pioneering studies in this field investigate how SNA techniques can be applied to examine the complex connections between objects in the context of SIoT networks. These studies aim to uncover these networks' interdependencies and emergent characteristics. Ultimately, it is crucial to address concerns related to trust and security. Pioneering research explores data privacy and security risks in SIoT ecosystems, offering solutions and highlighting ethical considerations for the new advancement [7].

The critical scholarly works related to SIoT research can be categorized into several areas. One area of focus is the architecture and components of SIoT, including its relationship with social networking and IoT technologies [8, 9]. Another area is trust management in SIoT, which involves establishing and maintaining trust relationships between IoT objects and users [10]. Service composition and discovery are other important aspects, and SIoT aims to provide efficient and scalable service selection and discovery mechanisms [1, 11]. Network navigability is also a significant research area, exploring how SIoT can leverage object relationships and local navigability to address scalability and interconnection challenges [12]. Additionally, studies have examined the integration of SIoT with other emerging technologies such as big data, cloud computing, and social networks [12].

Furthermore, recent studies have concentrated on many facets of SIoT, such as service composition and discovery, network navigability, architecture and components, platform and tools, relationship and trust management, and human activities [12]. The fusion of IoT and social technologies can augment cooperation capabilities and interactions between humans and computers. Nevertheless, there are still obstacles to overcome in the form of trust management and the requirement for networks that can be scaled and navigated [5, 7, 13]. The emergence of SIoT has also prompted the investigation of novel applications and networking services.

The current advancements and upcoming patterns in SIoT encompass the examination and representation of communication between intelligent devices, the influence of social characteristics on the spread of information, and the creation of dynamic cache methods [5]. Moreover, incorporating human social behaviors into physical IoT systems inside social IoT systems shows the potential to facilitate widespread connectivity among users [14]. In the context of SIoT, security is a crucial aspect. By utilizing social trust, it is possible to strengthen security without compromising the quality of experience for users [15]. Moreover, there has been a suggestion to employ social media users as social sensors to monitor and investigate the frequency and trends of pharmaceutical usage [16]. These advancements emphasize the significance of comprehending and using social characteristics and behaviors in applications of SIoT. These factors contribute to thoroughly comprehending the IoT in Smart Cities (SIoT) and its potential uses and difficulties.

2. METHODOLOGY

Understanding the current state and future research directions in any field demands a rigorous methodology to capture the existing knowledge. The rapidly increasing field of SIoT, where devices collaborate and interact socially, presents a unique challenge for understanding research trends and identifying future directions. While established approaches like systematic literature reviews [17] and meta-analysis [18] offer valuable insights, their scope can be limited. This study addresses this gap by employing bibliometric analysis. This robust approach leverages quantitative data like citations, keywords, and author collaborations to comprehensively map the intellectual landscape of a field [19].

Bibliometric analysis is a commonly used review approach that allows researchers to quantitatively analyze a collection of publications and objectively identify relevant similarities, relationships, and trends [20]. In the SIoT context, bibliometric analysis can be used to analyze the publication and citation trends, collaboration structures between authors, and the most frequently studied topics in the field [21]. It can also help identify key authors and their relationships and geographic expertise centers in the SIoT domain [22]. By using bibliometric analysis, researchers can gain insights into the current state of scientific research, explore issues, and identify prospects for further development in the field of SIoT [23, 24].

The bibliometric analysis is a valuable tool for understanding the research landscape and trends in the SIoT field, providing a foundation for future research endeavors. Through this approach, we aim to unveil the dominant research themes, emerging trends, and key players shaping the future of this transformative field and using Scopus database from 2012 to December 20, 2023 in social internet of things because it is the world's most extensive citation and abstract database of scholarly works from international publishers which provides a one-stop platform for scientific scholars. In

this study, the researcher utilized VOSviewer and *R* package, a bibliometric analysis tool available at www.vosviewer.com, to visualize bibliometric maps and networks. Furthermore, the data obtained from VOSviewer was utilized to generate graphs using Microsoft Excel.

2.1 Data source and selection criteria

This study leverages the comprehensive and indexed nature of the Scopus database to provide a robust foundation for the analysis. To narrow the focus on SIoT-related publications, several search queries were employed. As Figure 1 shows "Social Internet of Things," "Socially Aware Devices," "Collaborative Smart Objects," "IoT Social Networks," or "Interconnected Devices with Social Interactions" were used in the queries as combined relevant keywords limited the search to articles, conference papers, book chapters, reviews, and editorials in English coupled with publication date restrictions between 2012 and 2023. This timeframe captures the beginnings of SIoT research, its subsequent growth, and the potential emergence of new trends in recent years. The analysis may incorporate a year-by-year breakdown of publication trends, co-citation patterns, and keyword prominence to investigate temporal dynamics further, revealing the field's evolution over time.

By employing these robust data sources, carefully selected criteria, and a combination of powerful bibliometric techniques, this study seeks to provide a comprehensive and insightful analysis of the Social Internet of Things, laying the groundwork for further research and facilitating the responsible development of this transformative technology.

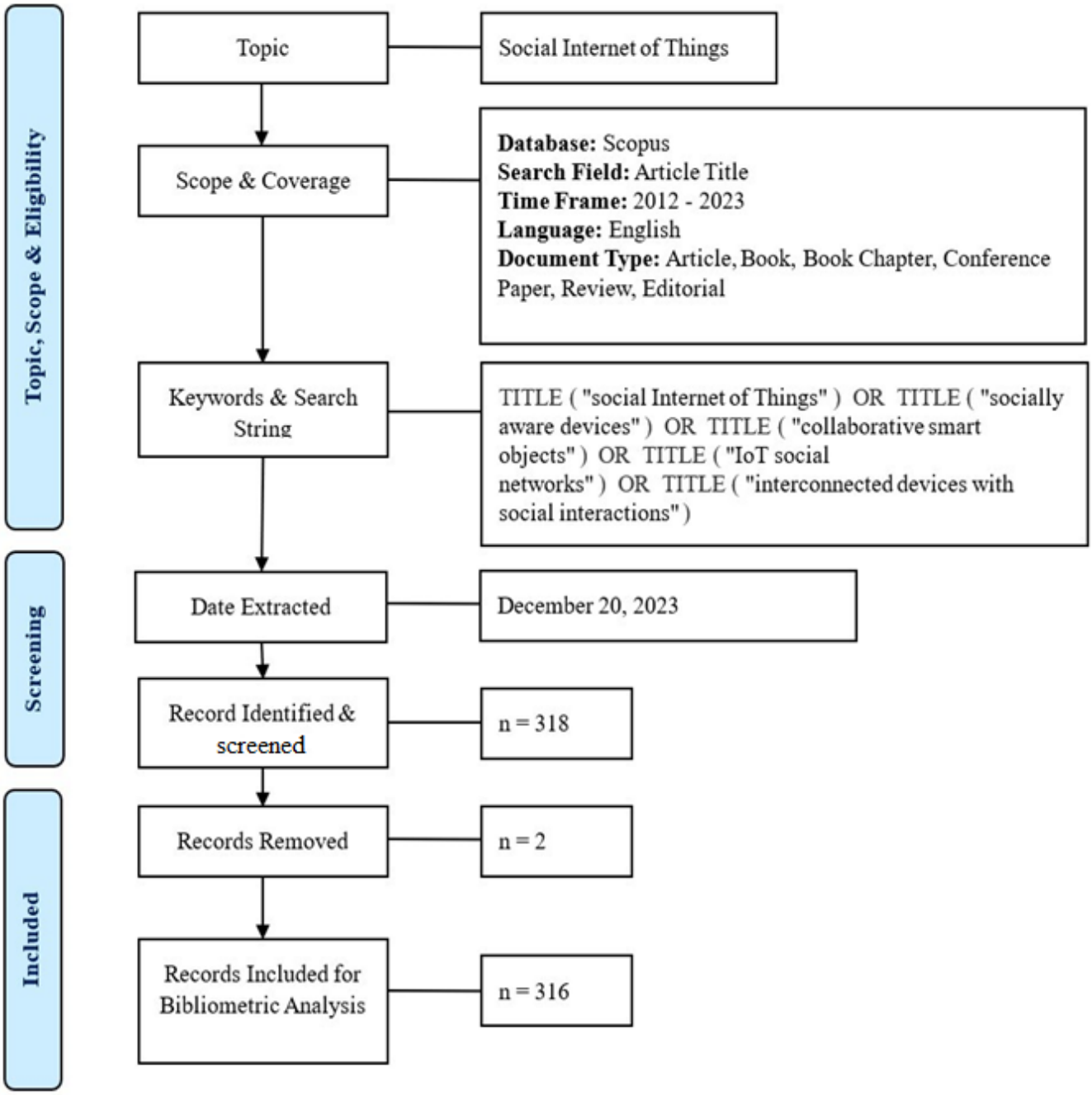

Figure 1. Search strategy

2.2 Data cleansing and preprocessing

Before the analysis, the retrieved publications were cleansed through a four-step process. First, duplicate papers were removed, eliminating redundancy and potential bias. Next, the remaining publications were thoroughly screened against the study's objectives, ensuring data relevance. Extracted data was then standardized and formatted for consistency, addressing inconsistencies and missing values. Finally, a validation step compared the preprocessed data against the sources, ironing out any remaining discrepancies. This thorough cleansing and preprocessing yielded a high-quality, reliable dataset of 316 publications ready for analysis.

3. RESULTS AND DISCUSSIONS

In this section, we explore the findings and discussions obtained from a thorough bibliometric analysis, uncovering the complex research network on the SIoT and its changing patterns. This section provides a clear direction for readers to navigate the various aspects of SIoT research, including citation trends and keyword co-occurrences. We aim to illuminate this dynamic and interdisciplinary area's current and future potential.

3.1 Main information

The data provided significant observations regarding bibliometric patterns in the SIoT between 2012 and 2023, as Table 1 shows. This analysis covered a comprehensive set of 316 documents obtained from 181 distinct sources, including journals, books, and other scholarly publications. During the stated period, research in SIoT has shown a significant Annual Growth Rate of 29.14%. The exponential growth demonstrates the dynamic nature of the discipline, which has attracted significant academic interest and has contributed to the advancement of knowledge in this area.

The mean age of the documents, computed as 4.27 years, indicates that the literature in SIoT is relatively new, reflecting the current nature of this interdisciplinary topic. Although the documents are new, they have a significant average citation rate of 21.91, demonstrating the research's influence and acknowledgment across the academic community. The documents contain 10,020 references, highlighting the extensive scholarly involvement and the interrelation of ideas within the SIoT study field. Upon examining the document contents, it becomes evident that using Keywords Plus (ID) and Author's Keywords (DE) showcases the vast array of terminology applied in the literature on SIoT. The presence of the 1866 Keywords Plus and 785 Author's Keywords underscores the intricate and multifaceted character of study subjects in the discipline, providing a nuanced viewpoint on the various dimensions researchers have investigated.

The collection includes contributions from 814 researchers, including 16 documents created by a single author. Nevertheless, collaborative efforts are widespread, as indicated by the mean of 3.83 co-authors per document. Moreover, international collaborations between authors constitute 32.28% of the total, highlighting the significant involvement of researchers from different countries and disciplines in SIoT research. The collection also contains a variety of document formats, including articles, book chapters, conference papers, editorials, and reviews. The diversity of SIoT research is evident in the comprehensive examination and discourse in articles and book chapters and the more prominent viewpoints presented in conference papers and reviews. As indicated below, the bibliometric trends in SIoT illustrate a dynamic and swiftly changing environment marked by expansion, cooperation, and varied research outcomes.

Table 1. Main information

Descriptions	Results
Main Information	
Timespan	2012:2023
Sources (Journals, Books, etc)	181
Documents	316
Annual Growth Rate %	29.14
Document Average Age	4.27
Average citations per doc	21.91
References	10020
Document Contents	
Keywords Plus (ID)	1866
Author's Keywords (DE)	785
Authors	
Authors	814
Authors of single-authored docs	16
Authors Collaboration	
Single-authored docs	17
Co-Authors per Doc	3.83
International Co-authorships %	32.28
Document Types	
Article	171
Book Chapter	15
Conference Paper	116
Editorial	5
Review	9
Timespan	2012:2023
Sources (Journals, Books, etc.)	181

3.2 Publication and citation trends of SIoT

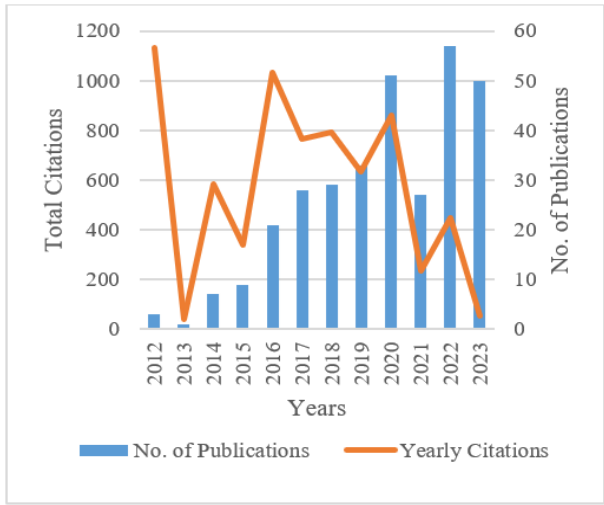

Figure 2. Publication and citation trends

Figure 2 demonstrates the development of the SIoT research landscape. Starting from the first efforts in 2012, there has been a steady and continuous increase throughout the decade, reaching a significant peak in recent years. Significantly, after 2020, the number of publications almost doubled, with the years 2022 and 2023 accounting for approximately half of the collection. This spike is associated with a noticeable increase in yearly citations, indicating higher productivity and a greater

impact on the broader academic community. This evolving field is experiencing rapid growth due to increased interest, possibly affected by external causes such as the pandemic's focus on social technologies or developments that enable the creation of SIoT. An in-depth examination of these time-based patterns enables researchers to traverse this changing landscape skillfully, find exciting areas for investigation, and guarantee their study's ongoing significance and influence during this ongoing acceleration.

3.3 Engaged authors

The study also explored Author Impact metrics as Table 2 shows, providing a detailed viewpoint on prominent personalities' intellectual contributions and influence in the selected field. Using well-established metrics such as the h-index and g-index, widely recognized as measures of scholarly impact, we identify Atzori L and Nitti M as notable contributors, differentiated by their remarkably high indices. Their extensive publication records and constantly referenced publications prove their lasting influence on the subject.

In addition to raw citation counts, the m-index offers valuable insights into the normalized influence of research over time. Girau R's impressive m-index demonstrates a continuous and unwavering contribution throughout their academic career. Ahmad A, Lee GM, and Paul A have h-indices and g-indices that are moderately lower than the leaders, indicating a potentially more limited range of influence.

Nevertheless, upon further examination, captivating subtleties become apparent. Iera A, despite having an average h-index, gets attention due to an exceptionally high overall citation count. Although fewer very influential publications may exist in the corpus, this difference indicates widespread acknowledgment among scholars. This observation is reinforced by Yang Y, whose increased m-index, although a lower total citation count, emphasizes a focused surge of influential publications in a short period.

This analysis aims to measure the different levels of impact among the authors examined and shed light on the complex aspects that underlie their scholarly pursuits. By transcending rudimentary citation counts, we better understand the various routes to academic influence, acknowledging extensive publication records and concentrated episodes of exceptionally significant work. This comprehensive strategy highlights the scholarly influence's ever-changing and sophisticated nature in the selected topic.

3.4 Conducive journals

The investigation into disseminating research on the SIoT uncovers a captivating story of academic commitment in this developing field of study. Table 3 presents important indicators from several sources, providing valuable information about the research environment in the field of the SIoT. Prominent contributors in the first quarter include notable publications such as "IEEE Internet of Things Journal" and "Future Generation Computer Systems." These journals showcase many published papers and have excellent citation rates. These indicators demonstrate the substantial effect and influence they have in SIoT research. The journals "IEEE Transactions on Computational Social Systems" and "IEEE Transactions on Network Science and Engineering" have impressive performance, focusing on the convergence of computational techniques and social systems in networking. The classification of journals into distinct quartiles (Q1 to Q4) offers a detailed comprehension of the varying levels of influence within the SIoT area, guaranteeing a comprehensive reference for academics in quest of influential platforms for their research. Based on the research study, this analysis helps you find the most desirable Q1 journals and navigate the changing field of SIoT research.

Table 2. Most productive authors in the area

Authors	h_index	g_index	m_index	TC	NP	PY_Start
ATZORI L	12	13	1	1991	13	2012
NITTI M	12	12	1	1988	12	2012
GIRAU R	8	11	0.667	689	11	2012
AHMAD A	7	7	0.875	411	7	2016
LEE GM	6	6	0.857	271	6	2017
PAUL A	6	6	0.75	348	6	2016
YANG Y	6	7	1.2	72	7	2019
AMIN F	5	7	0.833	141	7	2018
CHOI GS	5	5	0.833	205	5	2018
IERA A	5	6	0.417	1216	6	2012

TC= “Total Citation”; NP= “Number Publications”; PY= “Publication Year Start”

Table 3. Influential and frequently cited sources

Document Source	NP	TC	CPP	CS	SNIP	SJR	Ranking
Computer Communications	5	243	49	11	1.683	1.395	Q1
Future Generation Computer Systems	13	437	34	21.1	2.584	2.043	Q1
IEEE Access	11	302	27	9	1.422	0.926	Q1
IEEE Internet of Things Journal	25	746	30	17.4	2.844	3.747	Q1
IEEE Transactions on Computational Social Systems	7	98	14	10	1.698	1.351	Q1
IEEE Transactions on Network Science and Engineering	5	126	25	8.7	1.668	1.647	Q1
Lecture Notes in Computer Science	8	122	15	2.2	0.542	0.32	Q3
Lecture Notes in Electrical Engineering	5	14	3	0.6	0.158	0.147	Q4
Studies in Computational Intelligence	6	36	6	2	0.296	0.209	Q4
Wireless Personal Communications	6	78	13	4.5	0.908	0.545	Q2

NP= “Number Publications”; TC= “Total Citation”; CPP= “Citation Per Publication”; CS= “Cite Score” SNIP= “Source Normalized Impact per Paper; SJR= “Scimago Journal Ranking”.

3.5 Contributed countries

The analysis of bibliometric patterns in the field reveals unique contributions from different countries, as Figures 3 and 4 show, providing insights into the quantity and influence of research in this area. China leads in research production, with an impressive 94 documents. Nevertheless, China's total citations 1564 indicate substantial research, although the impact may vary. India closely trails behind with 58 documents, showcasing a significant research presence and influential contributions, as evidenced by a reasonably high citation rate per document.

South Korea's contribution to the case is notable, as it has submitted 36 documents and achieved an impressive overall citation count of 1165. This equilibrium implies a concentrated and impactful research endeavor in the domain of SIoT. The United States, a prominent participant in worldwide research, possesses a significant presence with 33 documents. Although the United States has fewer papers than China and India, the overall citations significantly influence SIoT literature.

Italy is notable for having 28 documents, indicating a relatively lower research output than certain other countries. Nevertheless, the remarkably elevated aggregate citation count of 2200 demonstrates that Italian research in SIoT is influential, extensively acknowledged, and referenced within the academic world.

Taiwan's contribution, consisting of 21 documents, exhibits a substantial influence, as evidenced by the cumulative citation count 404. Australia maintains an equitable representation in terms of the quantity and influence of its research, with 17 publications and a commendable overall citation count of 402. Saudi Arabia's 17 documents indicate a moderate level of research productivity, although there is an opportunity for further improvement in terms of effect.

The United Kingdom has significantly contributed to SIoT research, as evidenced by its 16 documents and total citation count of 485. With 13 documents, Iran has a relatively more minor research output but shows a notable impact, indicating a concentrated and potentially influential contribution to SIoT research.

China and India are at the forefront regarding research volume, whereas Italy is notable for its exceptionally influential research. The United States, South Korea, and several other nations make substantial contributions, each with its distinct combination of research volume and influence in the developing domain of the Social Internet of Things.

3.6 Most used keywords

The analysis of the literature on the SIoT and its integration into everyday computing environments has identified seven primary clusters as Figure 5 shows. These clusters are based on prominent phrases such as "Social Internet of Things," "Social Relationships," "IoT," "Internet of Things," "Trusted Computing," "Social Networking (Online)," and "Social Networks."

Cluster 1 emphasizes the importance of social interactions within IoT systems, focusing on machine learning, deep learning, data mining, and community detection for processing and understanding social data. Techniques like classification, efficiency, and recommender systems play a role in organizing and optimizing information in the context of SIoT. This cluster suggests a focus on leveraging advanced computational models to enhance the social aspects of IoT.

Cluster 2 highlights the importance of interdisciplinary perspectives and the role of artificial intelligence in SIoT, integrating social sciences with technology. The incorporation of semantics, machine learning, and cloud computing underscores the need for advanced AI-driven solutions to understand and manage IoT's social aspects.

Cluster 3 emphasizes network architecture and infrastructure within the context of IoT, focusing on constructing scalable and navigable networks. Concepts such as intelligent systems, traffic congestion, and average path length highlight considerations for efficient data dissemination and optimal network performance.

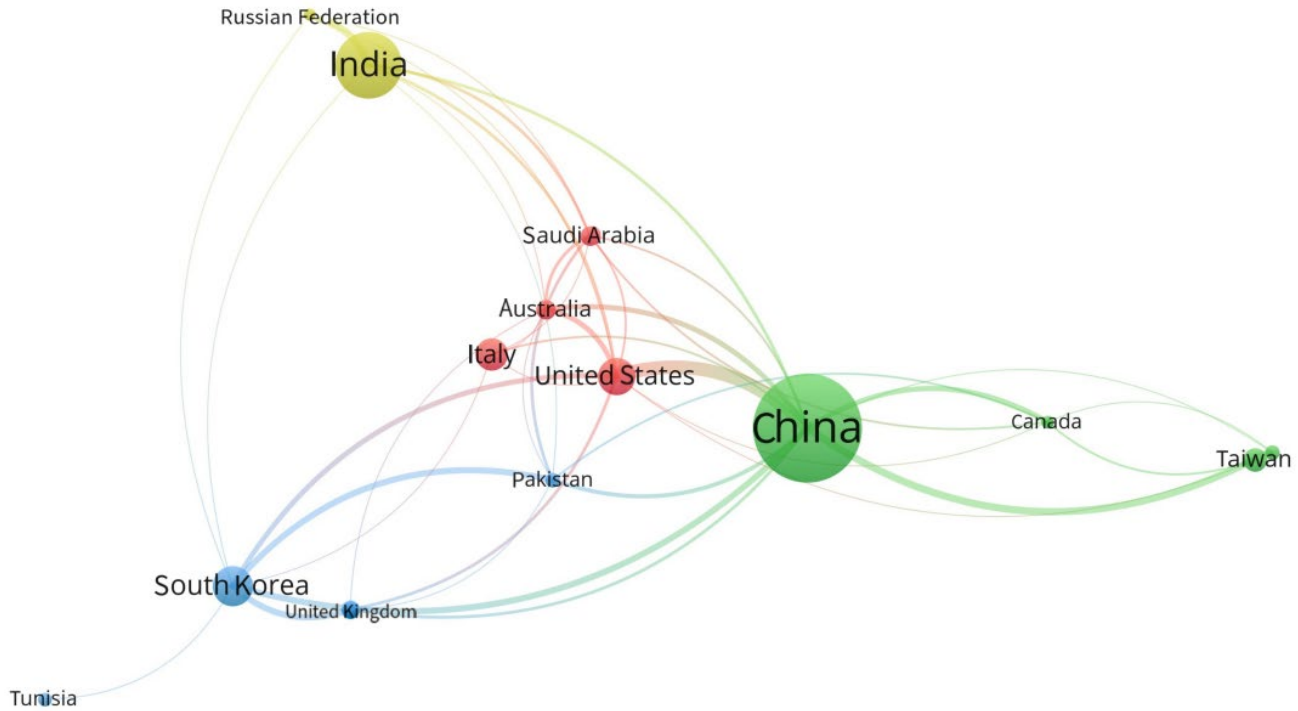

Figure 3. The contribution network of the countries

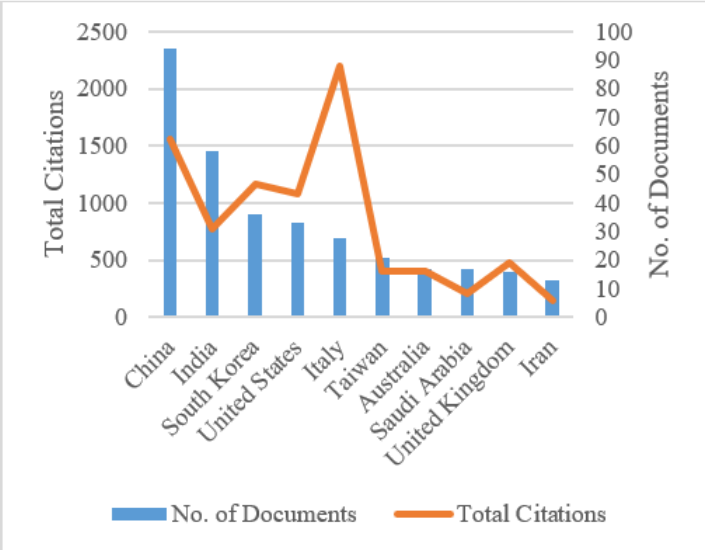

Figure 4. Publications by country

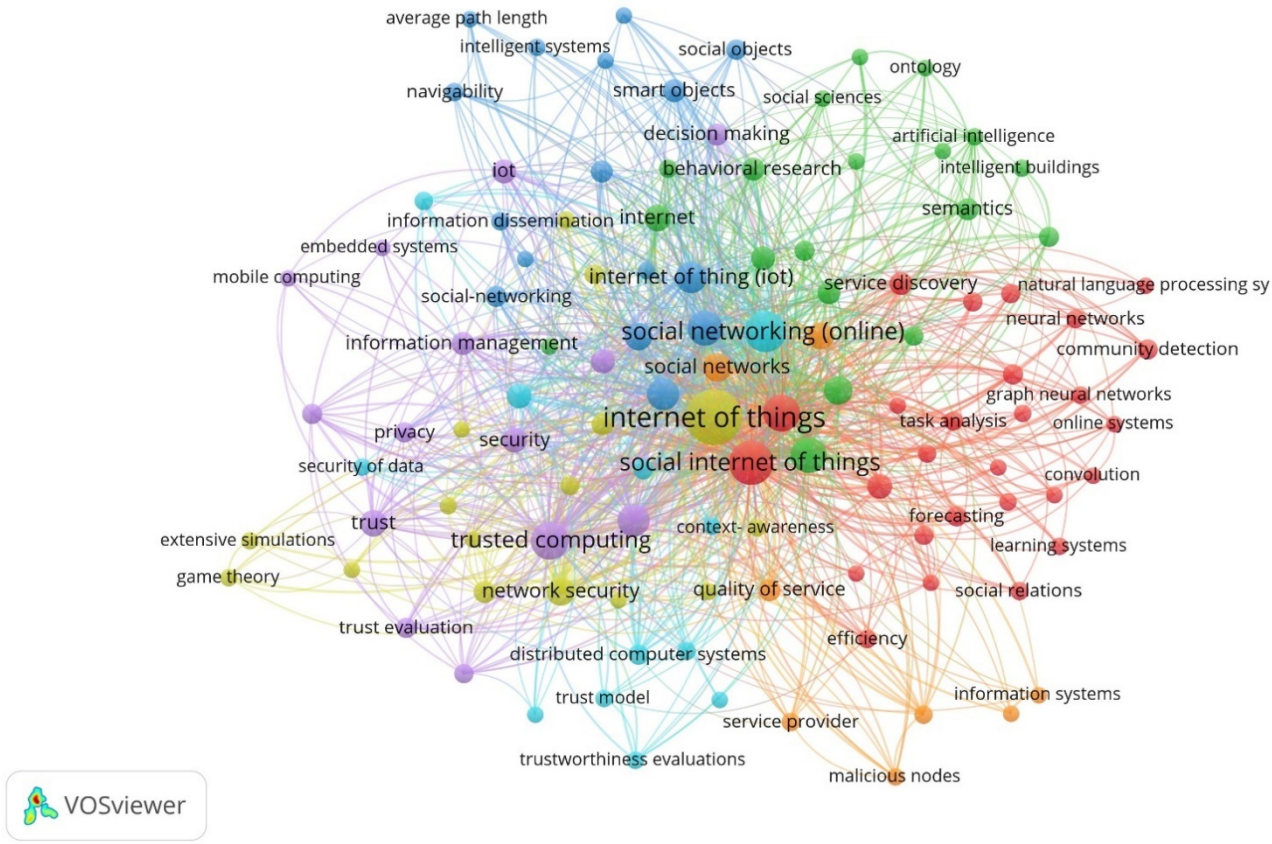

Figure 5. Keyword co-occurrence

Cluster 4 emphasizes the paramount importance of security and privacy in the broader landscape of IoT, stressing the need for secure and privacy-preserving solutions. Concepts such as trusted computing, cryptography, and authentication underscore comprehensive measures required to safeguard IoT systems from potential threats.

Cluster 5 revolves around trust management and blockchain technology within the IoT ecosystem, emphasizing the role of trust in shaping interactions and decisions within IoT networks. Concepts like decision-making, privacy, and trust evaluation further emphasize this role.

Clusters 6 and 7 focus on social networking and its integration into IoT and the SIoT. Cluster 6 emphasizes the widespread influence of technology on social interactions, while Cluster 7 emphasizes the importance of providing a dependable and responsive user experience within IoT environments.

4. CONCLUSIONS AND LIMITATIONS

The bibliometric examination of the literature on the SIoT demonstrated that this topic is vibrant and evolving quickly. Between 2012 and 2023, the time span experienced a significant yearly growth rate of 29.14%, indicating a rising interest and scholarly contributions in this interdisciplinary field. The cooperation among researchers from different nations is remarkable, as international co-authorships comprise 32.28% of the overall amount. The assortment of document formats, such as articles, book chapters, conference papers, editorials, and reviews, exemplify the complex and varied nature of SIoT research. Although the literature is relatively new, its average citation rate of 21.91 demonstrates its great effect and recognition within the academic world.

Based on their geographical distribution of contributions, China, the United States, and India are highlighted as significant contributors to SIoT research. The publication trends demonstrate a significant increase in output after 2020, coupled with a rise in citations, which suggests a greater level of attention and influence. Publications such as "The IEEE Internet of Things Journal" and "Future Generations Computer Systems" are recognized as influential forums for sharing research on the Security of the SIoT.

Authorship analysis revealed the notable contributors, namely Atzori L and Nitti M, who have made a lasting impression with their high h-indices and huge citation counts. The interconnected network of writers unveils complex relationships, demonstrating the collective endeavor to research the SIoT further.

The keyword analysis identified seven main clusters, prioritizing social interactions, interdisciplinary viewpoints, network design, security and privacy, trust management, and incorporating social networking into the IoT. These clusters thoroughly investigate SIoT from multiple perspectives, integrating sophisticated computational models, artificial intelligence, network architecture, and security issues.

Although the analysis is thorough, it is important to recognize certain limits. Bibliometric data relies on the sources and database (SCOPUS) utilized, which may result in omitting pertinent articles from other sources. The emphasis on keywords may need to be more concise about the intricacy of individual articles, and the omission of qualitative evaluations restricts a nuanced comprehension of research excellence. Future studies may investigate the integration of other databases and sophisticated metrics to provide a more complete picture of SIoT research. Furthermore, qualitative evaluations like expert perspectives and case studies could offer a deeper understanding of IoT technology's impact and real-world uses.

Subsequent investigations in the domain of SIoT could broaden the examination to encompass more contemporary literature, thereby offering a current viewpoint on emerging patterns. Integrating qualitative assessments, such as expert comments or peer reviews, would improve the evaluation of research quality. Moreover, exploring the actual applications and societal ramifications of SIoT research could enhance our comprehensive comprehension of its tangible influence in the real world. Furthermore, investigating nascent technologies such as edge computing and artificial intelligence in the context of the SIoT could offer valuable perspectives on developing research paths. It is crucial to conduct ongoing bibliometric analyses and foster interdisciplinary cooperation to capture the dynamic nature of the SIoT accurately.

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