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CONTROL OF UPPER LIMB REHABILITATION DEVICES: A BIBLIOMETRIC STUDY

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Abstract:

The study analyzes research trends, collaboration patterns, and key focus areas in the field of upper limb rehabilitation devices using bibliometric methods. With advancements in robotics and assistive technologies, these devices have become crucial for individuals with upper limb impairments, particularly stroke survivors. However, the rapid increase in publications necessitates a comprehensive understanding of research directions and influential contributions. This study used the Scopus Analyzer and VOSviewer software to examine a dataset of 1,208 publications. The Scopus analyzer provided insights into publication trends and author productivity. At the same time, VOSviewer was employed to map keyword occurrences and co-authorship networks, revealing the main topics and collaborative linkages across countries. The analysis highlights a steady increase in research output from 2015 to 2024, with a slight decline in the last two years, likely due to shifting research priorities or market saturation. Keywords such as "rehabilitation," "stroke," "upper limb," and "exoskeleton" indicate strong interest in assistive technology for motor recovery, while terms like "adaptive control" and "impedance control" emphasize the importance of control mechanisms tailored to patient needs. Additionally, international collaboration networks are led by countries like China, the United States, and Italy, reflecting their high research impact and extensive partnerships. In conclusion, this bibliometric analysis offers valuable insights into the progress and collaborative efforts within upper limb rehabilitation devices research, highlighting the interdisciplinary nature of the field and identifying potential areas for future exploration. This study serves as a reference for researchers aiming to develop further rehabilitation control solutions that enhance the quality of life for patients with upper limb impairments.

Keywords:

Upper Limb Rehabilitation Devices, Control Of Upper Limb Rehabilitation Device, Exoskeleton, Bibliometric Study, VOSviewer, Scopus Analyser

Introduction

The control of upper limb rehabilitation devices has seen significant advancements in recent years, driven by the integration of sophisticated control algorithms and wearable technologies. High-level control techniques, such as impedance/admittance-based strategies, adaptive control techniques, and physiological signal control, have been extensively reviewed and compared for their potential to enhance robotic training for upper limb rehabilitation. These strategies aim to provide tailored assistance based on the physical disability levels of users, thereby maximizing the therapeutic benefits (Miao et al., 2018). Wearable devices, particularly those utilizing inertial measurement units and wireless sensor networks, have shown promise in real-time motion monitoring and functional outcome assessment, further validating their clinical value in stroke rehabilitation (Lin et al., 2018).

Innovative control systems, such as the assistive control system embedded with force/torque sensors, have been developed to simulate human interaction under various rehabilitation modes, demonstrating positive outcomes in clinical trials (Chen *et al.,* 2016). Additionally, artificial intelligence-based wearable robotic exoskeletons have emerged, leveraging neural networks and adaptive algorithms to enhance the rehabilitation process through improved interaction and data fusion from multiple sensors (Vélez-Guerrero *et al.*, 2021). Robust motion control architectures address the uncertainties and disturbances inherent in exosuits, ensuring precise and stable control during rehabilitation exercises (Pont-Esteban, *et al.,* 2022). These advancements collectively highlight the potential of combining different control strategies and technologies to deliver effective and personalized upper limb rehabilitation.

Literature Review

He *et al.* (2024) developed a model-free super-twisting terminal sliding mode controller (MF-STTSMC) to address dynamic complexities like backlash hysteresis in upper limb exoskeletons. Their findings suggest that MF-STTSMC significantly outperforms methods such as time-delay estimation-based proportional-derivative control in reducing design complexity, making it particularly suitable for adaptive rehabilitation environments (He *et al.*, 2024). Abdallah and Bouteraa (2024) advanced adaptive frameworks by introducing a fuzzy logic-based pain detection system within an optimized stimulation control system (OSCS). This system prioritizes patient comfort by adjusting stimulation based on individual pain thresholds, an approach crucial for minimizing overexertion. However, since pain sensitivity varies among patients, reliance on pain detection may limit its effectiveness across diverse populations (Abdallah & Bouteraa, 2024).

Li *et al.* (2024) proposed a multi-sensor fusion-based mirror adaptive assist-as-needed (AAAN) strategy that combines biological signals and motion data for personalized support. Through Kalman filtering, their approach adapts in real-time to different recovery stages, fostering active patient involvement (Li *et al.,* 2024). Jiang *et al.* (2024) introduced impedance learning-based hybrid control, which offers variable impedance regulation to enhance robot stability without direct force measurements. By validating this control strategy with a Lyapunov-based stability criterion, they demonstrated its robustness in uncertain scenarios, making it a valuable

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tool for consistent therapeutic intervention (Jiang *et. al,* 2024). Furthering control strategies, Zarrin *et al.* (2024) developed a variable-admittance assist-as-needed controller focused on regulating wrist and upper arm interactions to allow for minimal assistance based on patient performance and intention (Zarrin *et al.*, 2024). Meanwhile, effective for patient-driven programs, the system's extensive calibration requirements might affect efficiency for patients with varied motor functions. Pang *et al.* (2024) introduced a four-degree-of-freedom rehabilitation robot using a backpropagation neural network (BPNN) and particle swarm optimization (PSO) for adaptive control, enabling dynamic parameter adjustments for movement accuracy (Pang *et al.*, 2024). Cai *et al.* (2024) developed a compensation-corrective adaptive control (CCAC) strategy to counter trunk compensation in stroke rehabilitation, enhancing movement precision by reducing compensatory postures (Cai *et al.*, 2024).

A major research focus also lies in managing uncertainties and disturbances in exoskeleton control. Wang *et al.* (2024) reviewed upper limb rehabilitation control methods, emphasizing the challenges posed by dynamic model complexities, external disturbances, and accurate motion intention recognition (Wang *et al.*, 2024). Guo *et al.* (2024) added to this area by designing an adaptive hybrid-mode assist-as-needed (AHMAAN) control that combines assistive and resistive modes with dynamic adjustments via fuzzy logic, allowing flexibility across varied patient conditions (Guo *et. al*, 2024). For optimization, Bhaskarwar *et al.* (2024) explored an Enhanced Active Disturbance Rejection Controller (EADRC), which uses nonlinear state error feedback and an extended state observer to improve tracking of sinusoidal trajectories in upper limb exoskeletons, closely mimicking natural movement (Bhaskarwar *et. al*, 2024). Zhang *et al.* (2024) enhanced this concept by integrating pneumatic artificial muscles (PAM) actuators with neural network-based control, which adapts dynamically to the complex hysteresis typical of PAM systems (Zhang *et al*., 2024). This iterative learning capability strengthens control adaptiveness, especially beneficial for long-term rehabilitation.

Despite these advancements, there are still gaps in long-term validation, particularly for adaptive controllers, which are largely tested in simulated environments rather than extended clinical settings (Zhu *et al.*, 2024), (Pang *et al.*, 2024). Most studies, such as those by Cai *et al.* (2024) and Guo *et al.* (2024), are limited to single-joint control, leaving room for more complex multi-joint control strategies that could better replicate human movement. The exploration of model-free and data-driven approaches, as seen in the works of He *et al.* (2024) and Zhang *et al.* (2024) also offers promise but requires broader validation across diverse patient populations. In summary, while recent studies reveal substantial progress in adaptive, disturbance-resistant, and model-free control solutions for upper limb rehabilitation, further empirical research in real-world settings and with multi-joint designs could significantly improve therapeutic effectiveness in clinical practice.

Research Question

The following research questions are answered in this bibliometric study:

- What are the research trends in the control of upper limb rehabilitation devices according to the year of publication?
- What are the percentage of documents by subject of research?
- Who writes the most cited articles?
- Who is the top 10 authors based on citation by research?
- What are the popular keywords related to the study?
- What are co-authorship countries' collaboration?

Methodology

Bibliometrics involves gathering, managing, and analyzing information from scientific publications to understand better trends and patterns in research (Alves, Borges, & De Nadae, 2021; Assyakur & Rosa, 2022; Verbeek, Debackere, Luwel, & Zimmermann, 2002). This approach includes general statistics, such as which journals publish the work, the years of publication, and identifying key authors (Wu & Wu, 2017). It also includes more advanced techniques, like document co-citation analysis, which helps reveal connections between studies. Conducting a thorough literature review requires an iterative process: finding the right keywords, searching the literature, and carefully analyzing sources to create a complete bibliography and ensure reliable findings (Fahimnia, Sarkis, & Davarzani, 2015).

This study focuses on high-impact publications, as they provide valuable insights into the theories shaping this research field. To ensure the data's reliability, the SCOPUS database is used for data collection (Al-Khoury *et al.*, 2022; di Stefano, Peteraf, & Veronay, 2010; Khiste & Paithankar, 2017). Elsevier's Scopus, known for its broad coverage, made it possible to collect publications which are then used in the analysis.

Data Search Strategy

The research utilized a systematic screening process to identify appropriate search terms for collecting relevant articles. The initial search was conducted in the Scopus database using the title-abstract-keywords (control AND ("upper limb rehab*" OR "upper extremity rehab*" OR "*arm* rehab*" OR "shoulder* rehab*" OR "elbow* rehab*" OR "wrist* rehab*" OR "hand* rehab*") AND (robot* OR device* OR equipment OR instrument* OR exoskeleton*)) which yielded 1,723 articles. A refined search string was developed that included publication year restrictions (2015-2024), document types (article, conference paper, conference review, review, book chapter), source types (journal, conference proceeding, book series), and language (English only). This final refined search resulted in 1208 articles, which formed the basis for this bibliometric analysis. The study included all relevant Scopus-indexed articles about the control of upper limb rehabilitation devices published until November 2024. Tables 1 and 2 shows the search string and selection criterion in searching.

Table 1: Search String.

Scopus	TITLE-ABS-KEY (control AND ("upper limb rehab*" OR "upper extremity rehab*" OR "*arm* rehab*" OR "shoulder* rehab*" OR "elbow* rehab*" OR "wrist* rehab*" OR "hand* rehab*") AND (robot* OR device* OR equipment OR instrument* OR exoskeleton*)) AND (LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2024)) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j") OR LIMIT-TO (SRCTYPE, "p") OR LIMIT-TO (SRCTYPE, "k")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "cr") OR LIMIT-TO (DOCTYPE, "re") OR LIMIT-TO (DOCTYPE, "ch")).

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Table 2: Selection Criterion In Searching.

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2015–2024	< 2015
Source type	Journal, conference proceedings, book series	Book

Data Analysis

VOSviewer, a widely recognized bibliometric software developed by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands, is known for its user-friendly interface and robust analytical capabilities (van Eck & Waltman, 2017) (van Eck & Waltman, 2010). The software is extensively employed for the visualization and analysis of scientific literature, particularly excelling in generating intuitive network visualizations, clustering interrelated items, and creating density maps. Its multifunctionality enables the exploration of co-authorship, co-citation, and keyword co-occurrence networks, thereby offering researchers a detailed perspective on various research landscapes. With its interactive interface and continuous updates, VOSviewer ensures the efficient and dynamic handling of large-scale datasets. The software's ability to compute bibliometric metrics, customize visualizations, and integrate with diverse bibliometric data sources establishes it as an indispensable tool for researchers seeking insights into complex academic domains.

A key strength of VOSviewer lies in its ability to transform complex bibliometric datasets into visually interpretable maps and charts. Its focus on network visualization makes it highly effective in clustering related elements, analyzing keyword co-occurrence patterns, and constructing density maps. The software's intuitive design allows novice and experienced researchers to navigate research landscapes seamlessly. Ongoing updates to VOSviewer ensure it maintains its relevance and leadership in bibliometric analysis by enabling metrics computation and tailored visualizations. Additionally, its compatibility with various types of bibliometric data, such as co-authorship and citation networks, further underscores its role as a versatile and essential tool for uncovering significant patterns and insights in scholarly research. Datasets containing information on publication year, titles, authors, journals, citations, and keywords in PlainText format were extracted from the Scopus database, covering the period from 2020 to December 2023. These datasets were subsequently analyzed using VOSviewer (version 1.6.19), which facilitated the creation of bibliometric maps through clustering and mapping techniques. As an alternative to the Multidimensional Scaling (MDS) approach, VOSviewer employs a methodology designed to position items in low-dimensional spaces, ensuring that the spatial proximity between items accurately represents their similarity and interrelatedness (van Eck & Waltman, 2010). Meanwhile, sharing some conceptual similarities with MDS (Appio, Cesaroni, & Di Minin, 2014), VOSviewer diverges in its approach by adopting normalization techniques better suited for co-occurrence data. For example, it applies the association strength (AS_{ij}), which is calculated as follows (Van Eck & Waltman, 2007):

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$$AS_{ij} = \frac{c_{ij}}{w_i w_j}, \qquad (1)$$

where c_{ij} denotes the number of co-occurrences of items *i* and *j*. w_i and w_j denote either the total number of occurrences of items *i* and *j* or the total number of co-occurrences of these items.

Results and Findings

What are the Research Trends in the Control of Upper Limb Rehabilitation Devices according to the Year of Publication?

The trend in publications on "Control of Upper Limb Rehabilitation Devices" from 2015 to 2024, as shown in Figure 1, demonstrates a general increase in research interest over the years. Starting from around 80 documents in 2015, there is a steady rise, with a notable spike in 2016 and a peak observed in 2022, reaching close to 170 publications. This upward trend may indicate growing attention in the field of upper limb rehabilitation, potentially due to advancements in robotics, control systems, and increasing demand for rehabilitation solutions addressing upper limb impairments. However, the decline observed from 2022 to 2024 suggests a slight decrease in publication activity. This could be due to several factors, such as market saturation, shifts in research funding priorities, or the completion of significant projects within this period. Despite this, the overall upward trend across the years reflects a sustained interest in improving and innovating upper limb rehabilitation technologies, which remain relevant in both clinical and home-based settings.

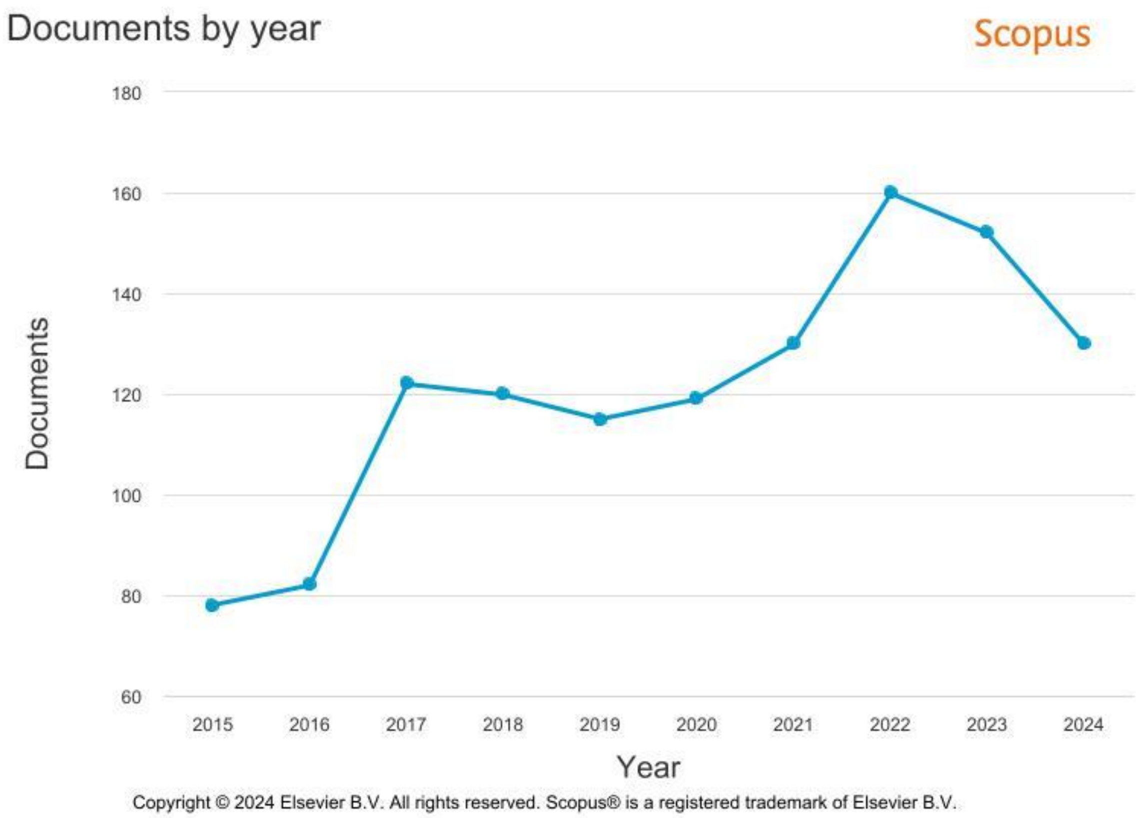

Figure 1: Number Of Documents Published For Control Of Upper Limb Rehabilitation Devices From 2015 To 2024.

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What are the Percentage of Documents by Subject of Research?

Referring to Figure 2, the distribution of publications by subject area for "Control of Upper Limb Rehabilitation Devices" shows that the majority of research lies within Engineering (30.5%) and Computer Science (24.6%). This is expected, as the development of rehabilitation devices involves engineering principles, control systems, and computational algorithms to enhance device functionality and effectiveness. The significant focus on these areas highlights the technical and interdisciplinary nature of this research domain, where engineering solutions are combined with computational approaches. Other fields also contribute to this research, although to a lesser extent. Mathematics (10.7%) plays a role, potentially due to its applications in modeling, control algorithms, and optimization techniques. Medicine (8.8%) represents the clinical relevance of this work, as these devices directly benefit patient care and therapeutic practices. The presence of subjects like Physics, Materials Science, and Neuroscience suggests that developing these devices also involves understanding the biomechanical, material, and neurological factors involved in upper limb function and rehabilitation. This distribution underscores the collaborative efforts across disciplines to address the complex requirements of upper limb rehabilitation through both technical and clinical innovations.

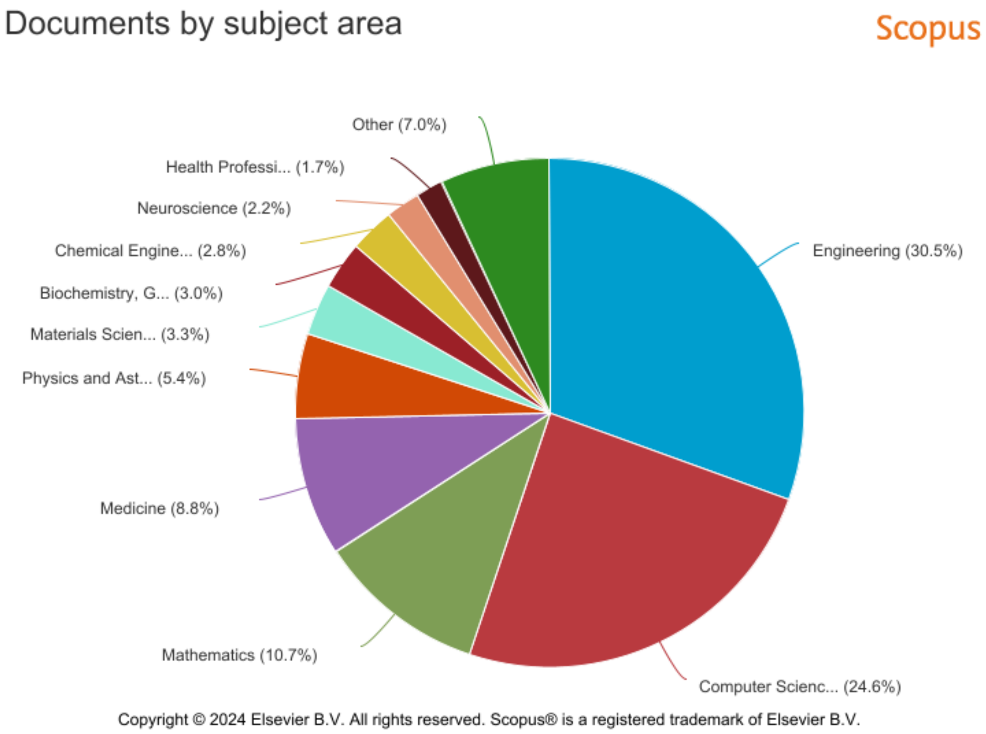

Figure 2: Percentage Of Documents By Subject Of Research In Control Of Upper Limb Rehabilitation Devices.

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Who Writes the Most Cited Articles?

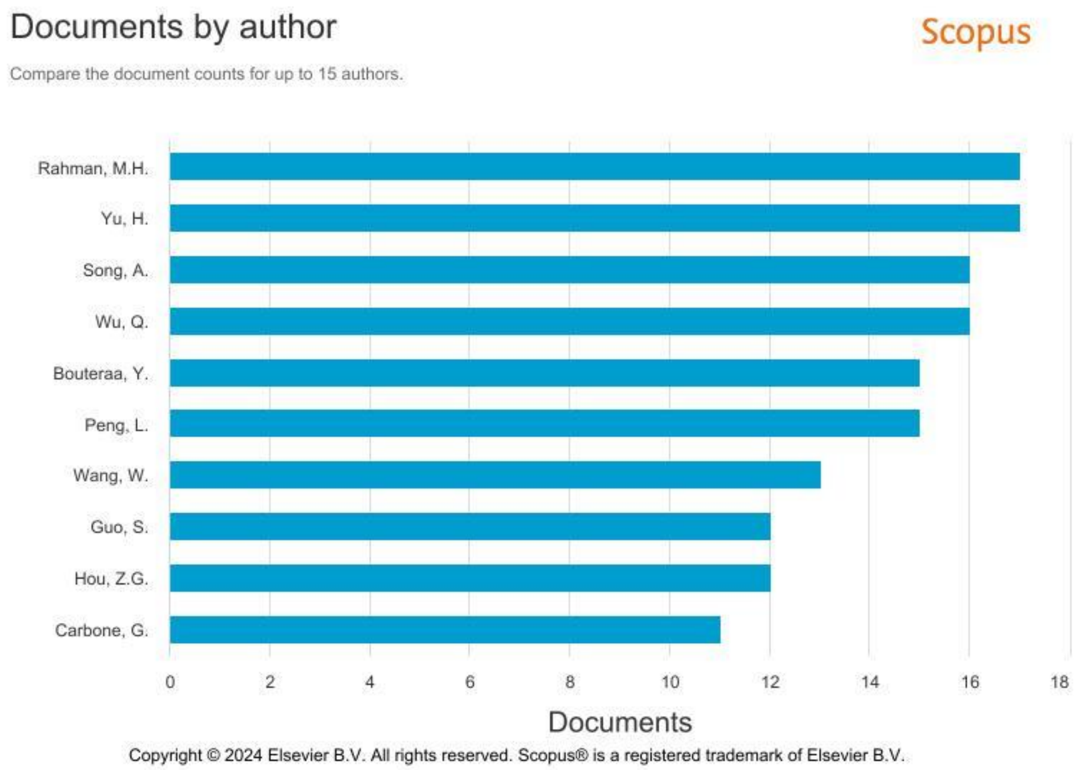

Figure 3: Document Count By Author In The Field Of Control Of Upper Limb Rehabilitation Devices.

Table 3: Document Count by Author in the field of Control of Upper Limb Rehabilitation Devices.

Author	Number of Document	Percentage %
Rahman, M.H.	17	1.407285
Yu, H.	17	1.407285
Song, A.	16	1.324503
Wu, Q.	16	1.324503
Bouteraa, Y.	15	1.241722
Peng, L.	15	1.241722
Wang, W.	13	1.076159
Guo, S.	12	0.993377
Hou, Z.G.	12	0.993377
Carbone, G.	11	0.910596

The document count by the author in the field of "Control of Upper Limb Rehabilitation Devices," as shown in Figure 3 and Table 3, reveals a concentration of contributions from specific researchers, indicating leading figures and active contributors in this area. M.H. Rahman and H. Yu top the list, each with 17 documents reflecting their significant involvement in advancing knowledge and innovations within upper limb rehabilitation control. This suggests they may have established research groups or consistent funding sources, enabling

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sustained output over time. The prominence of these authors highlights a potential influence on the development and direction of research trends in the field. Authors like A. Song and Q. Wu also feature prominently, each with 16 documents, showcasing a strong commitment to the control of upper limb rehabilitation research. The spread among the top 10 authors suggests a collaborative but specialized community, with multiple experts contributing to various aspects of control systems, robotics, and rehabilitation technologies. This trend of concentrated authorship implies that these researchers could serve as key references for further studies, providing foundational knowledge and innovations that can guide new researchers and interdisciplinary projects in this rapidly evolving field.

Who is the Top 10 Authors based on Citation by Research?

Referring to Table 4, the data reveals that the most influential paper in this field is by Polygerinos *et al.* (2015) on soft robotic gloves, published in Robotics and Autonomous Systems, with an impressive 1,250 citations. This paper significantly outperforms others in the dataset, having approximately six times more citations than the second most-cited paper. This suggests that soft robotics approaches to rehabilitation have garnered substantial interest from the research community, particularly for hand rehabilitation applications. The publication years range from 2015 to 2021, with the majority of papers (7 out of 10) published between 2015-2018, indicating a particularly productive period in this field. The research topics cover diverse aspects of upper limb rehabilitation, including brain-computer interfaces and exoskeletons. Notably, there is a strong focus on control systems and smart technologies, as evidenced by papers from Pehlivan *et al.* (2016) and Yang *et al.* (2018), which received 208 and 153 citations, respectively. The papers are published across various prestigious journals, with no single journal dominating the field. The publication venues range from specialized robotics journals (IEEE Transactions on Robotics, International Journal of Robotics Research) to rehabilitation-focused journals (Journal of NeuroEngineering and Rehabilitation) and broader engineering publications (Proceedings of the IEEE).

Table 4: Top 10 Authors based on Citation by Research.

Authors	Title	Year	Source Title	Cited by
Polygerinos P.; Wang Z.; Galloway K.C.; Wood R.J.; Walsh C.J. (Polygerinos *et al.*, 2015)	Soft robotic glove for combined assistance and at-home rehabilitation	2015	Robotics and Autonomous Systems	1250
Pehlivan A.U.; Losey D.P.; Omalley M.K. (Pehlivan *et al.*, 2016)	Minimal Assist-as-Needed Controller for Upper Limb Robotic Rehabilitation	2016	IEEE Transactions on Robotics	208
Yang G.; Deng J.; Pang G.; Zhang H.; Li J.; Deng B.; Pang Z.; Xu J.; Jiang M.; Liljeberg P.; Xie H.; Yang H. (Yang *et al.*, 2018)	An IoT-Enabled Stroke Rehabilitation System Based on Smart Wearable Armband and Machine Learning	2018	IEEE Journal of Translational Engineering in Health and Medicine	153
Babaiasl M.; Mahdioun S.H.; Jaryani P.; Yazdani M. (Babaiasl *et al.*, 2016)	A review of technological and clinical aspects of robot-aided rehabilitation of upper-extremity after stroke	2016	Disability and Rehabilitation: Assistive Technology	142
Agarwal P.; Fox J.; Yun Y.; O'Malley M.K.;	An index finger exoskeleton with series elastic actuation	2015	International Journal of	139

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Deshpande A.D. (Agarwal *et al.*, 2015)	for rehabilitation: Design, control and performance characterization		Robotics Research	
Baniqued P.D.E.; Stanyer E.C.; Awais M.; Alazmani A.; Jackson A.E.; Mon-Williams M.A.; Mushtaq F.; Holt R.J. (Baniqued *et al.*, 2021)	Brain-computer interface robotics for hand rehabilitation after stroke: a systematic review	2021	Journal of NeuroEngineering and Rehabilitation	118
Riani A.; Madani T.; Benallegue A.; Djouani K. (Riani *et al.*, 2018)	Adaptive integral terminal sliding mode control for upper-limb rehabilitation exoskeleton	2018	Control Engineering Practice	118
Ben I.; Bouteraa Y.; Rekik C. (Ben *et al.*, 2017)	Design and development of 3d printed myoelectric robotic exoskeleton for hand rehabilitation	2017	International Journal on Smart Sensing and Intelligent Systems	117
Kimberley T.J.; Pierce D.; Prudente C.N.; Francisco G.E.; Yozbatiran N.; Smith P.; Tarver B.; Engineer N.D.; Dickie D.A.; Kline D.K.; Wigginton J.G.; Cramer S.C.; Dawson J. (Kimberley *et al.*, 2018)	Vagus nerve stimulation paired with upper limb rehabilitation after chronic stroke: A blinded randomized pilot study	2018	Stroke	109
Ang K.K.; Guan C. (Ang & Guan, 2015)	Brain-computer interface for neurorehabilitation of upper limb after stroke	2015	Proceedings of the IEEE	100

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What are the Popular Keywords Related to the Study?

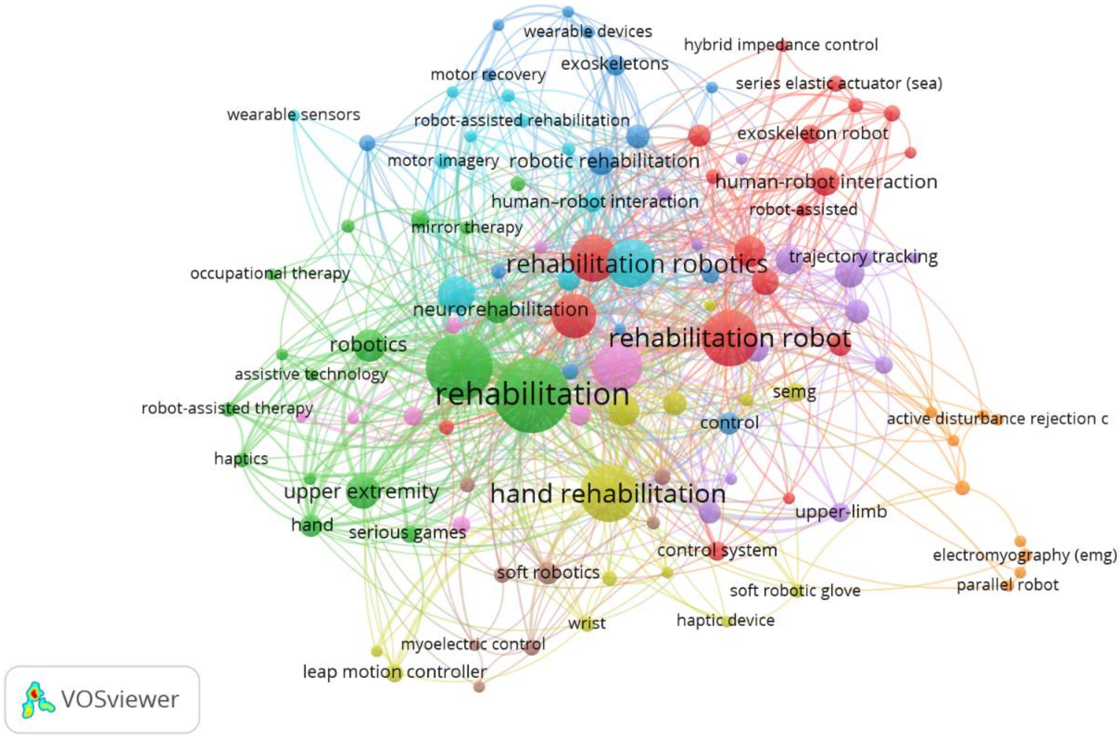

Figure 4: Network Visualization Map Of Keywords' Co-Occurrence For The Study On Control Of Upper Limb Rehabilitation Devices.

Figure 4 shows a detailed keyword analysis for the bibliometric study on "control of upper limb rehabilitation devices." High-occurrence terms like "rehabilitation" (168 occurrences, 282 link strength) and "stroke" (132 occurrences, 269 link strength) emphasize the core focus on rehabilitation needs and the prevalence of stroke as a primary application area. This concentration highlights the importance of these devices for individuals recovering from stroke-related impairments. Additionally, terms like "upper limb" (57 occurrences, 104 link strength) and "exoskeleton" (70 occurrences, 132 link strength) underline the widespread use of robotic and assistive devices for upper limb support and mobility enhancement in rehabilitation contexts. The table also includes terms such as "control" (15 occurrences, 25 link strength), "adaptive control" (23 occurrences, 36 link strength), and "impedance control" (29 occurrences, 45 link strength). Adaptive control and impedance control are essential in the control of rehabilitation devices. This suggests focusing on personalized rehabilitation, where the control mechanisms adjust dynamically to optimize therapy outcomes.

What are Co-authorship Countries' Collaboration?

Figure 5 provides insights into international collaborations on the control of upper limb rehabilitation device research, highlighting significant contributions from various countries. China stands out with the highest number of documents (394) and citations (3898), demonstrating its leading role in research productivity and impact. Additionally, it has a high total link strength of 99, indicating substantial international collaboration. Following China, the United States and Italy also show strong involvement, with 127 and 109 documents, respectively. The United States, with 3728 citations and a link strength of 82, suggests influential research and significant international partnerships. Italy's link strength of 50

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highlights its collaborative efforts within the global research community. Countries such as Canada, Australia, and the United Kingdom also play substantial roles in this research area, with each country producing a notable number of documents and accumulating significant citations. Canada, with 46 documents and 438 citations, and Australia, with 35 documents and 608 citations, reflect high research quality and international collaboration. The United Kingdom, with 64 documents, ranks second in total link strength (65), indicating robust collaborative networks and a substantial research impact. Other European countries like Germany and France, despite lower document counts, maintain strong citation numbers and moderate link strengths, illustrating valuable but more selective international partnerships. Smaller research contributors, such as Malaysia, Hong Kong, and Singapore, exhibit specialized contributions with moderate document counts and relatively high citation rates. For instance, Hong Kong has 676 citations from 26 documents, suggesting high-impact research within its niche. Middle Eastern countries like Saudi Arabia and the United Arab Emirates also show notable link strengths, particularly Saudi Arabia, with a total link strength of 24, signaling active engagement in international collaborations. This distribution reflects global interest in upper limb rehabilitation device research, with prominent contributions from Asia, North America, and Europe, while Middle Eastern and Southeast Asian nations emerge as growing contributors to this field.

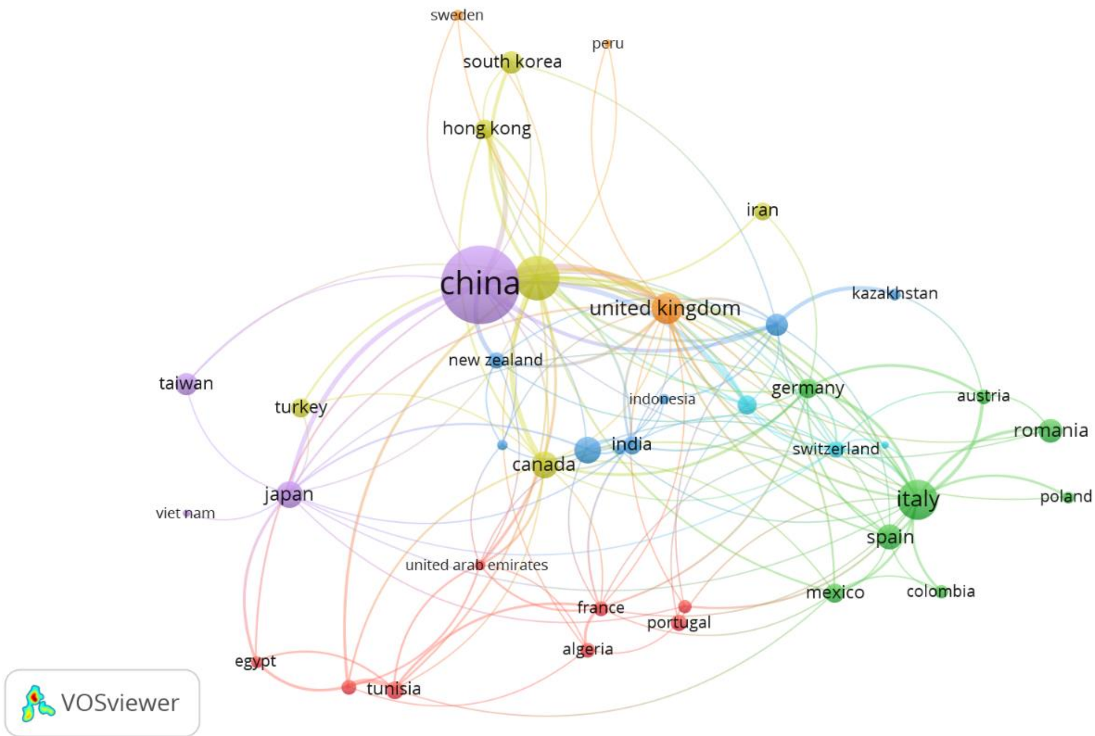

Figure 5: Co-authorship Countries' Collaboration In The Study Of Control Of Upper Limb Rehabilitation Devices.

Discussion and Conclusion

The findings from this bibliometric analysis provide a clear picture of the evolution, key contributors, thematic focus, and influential works in the field of upper limb rehabilitation devices. Research activity on this topic has generally increased over the past decade, with notable peaks and a recent slight decline, indicating both the maturation of the field and

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potentially shifting research priorities. The upward trend overall suggests sustained interest, possibly fueled by technological advancements and the growing need for improved rehabilitation solutions. The contributions of leading authors have significantly shaped the field, with a small group of researchers producing highly cited papers that guide current understanding and further investigation into device control for rehabilitation.

The interdisciplinary nature of this research is evident, with engineering and computer science dominating the publications, underscoring the technical complexity of developing control systems for rehabilitation devices. The diversity of publication venues and document types reflects this interdisciplinary approach, combining insights from robotics, neuroscience, and rehabilitation medicine to create comprehensive rehabilitation solutions. Highly cited papers, such as those exploring soft robotic technologies, emphasize the field's focus on innovative, patient-centered applications like hand rehabilitation, which continue to drive academic interest and potential clinical impact. This analysis highlights not only the progress made but also the collaborative, cross-disciplinary efforts required to address complex rehabilitation needs effectively.

There is an increasing global focus on upper limb rehabilitation devices, with key research trends centering around rehabilitation applications, particularly for stroke patients, and advancements in control strategies. Popular keywords such as "rehabilitation," "stroke," "upper limb," and "exoskeleton" highlight the emphasis on developing assistive technologies to support mobility and recovery, while terms like "adaptive control" and "impedance control" indicate a focus on tailoring device control functions to individual patient needs. International collaboration is strong in this field, led by significant contributions from China, the United States, and Italy, which produce high-impact research and maintain extensive global partnerships. Countries like Canada, Australia, and the United Kingdom also demonstrate robust collaboration networks, while emerging contributors from Asia and the Middle East show increasing engagement. This international cooperation underscores the interdisciplinary and cross-border efforts required to advance rehabilitation technologies and improve patient outcomes.

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