Utilization of Sensor technology as a Sport Technology Innovation in Athlete Performance Measurement: Research Trends

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Abstrak

Revolusi industri 4.0 telah membawa kemajuan teknologi yang pesat dalam teknologi olahraga, bertujuan untuk meningkatkan performa atlet dan memantau perkembangannya. Inovasi-inovasi tersebut berdampak pada industri olahraga, namun baru dirasakan di negara-negara maju. Studi yang ada tentang kewirausahaan, extended reality, e-tekstil, dan Inertial Movement Unit (IMU) telah mengeksplorasi berbagai aspek teknologi olahraga. Namun, belum ada ulasan yang berfokus pada penggunaan teknologi sensor dalam performa olahraga. Studi ini menganalisis secara bibliometrik penelitian tentang teknologi olahraga dari tahun 2008-2023, mengungkap pola pertumbuhan, makalah terkemuka, penulis terkemuka, jurnal, institusi, dan negara. Visualisasi dilakukan dengan menggunakan VOSviewer dan RStudio. Temuan ini memberikan wawasan bagi para peneliti dan pembaca untuk mengidentifikasi evolusi dan pertumbuhan topik teknologi sensor olahraga serta mengidentifikasi bidang penelitian saat ini dan yang potensial. China menjadi negara paling produktif dengan menyumbang 17 publikasi terkait teknologi olahraga, sedangkan Inggris menjadi negara paling berdampak dengan 474 kutipan.

***Kata kunci**— Performa atlet, teknologi olahraga, bibliometrik, analisis kata bersama, tren penelitian*

Abstract

The Industrial Revolution 4.0 has led to rapid technological advancements in sports technology, aiming to improve athlete performance and monitor developments. These innovations have had an impact on the sports industry, but have only been felt in developed countries. Existing studies on entrepreneurship, extended reality, e-textiles, and inertial movement units (IMU) have explored various aspects of sports technology. However, no review has focused on sensor technology's use in sports performance. This study bibliometrically evaluates sports technology research from 2008 through 2023, identifying trends in growth, notable publications, top authors, journals, institutions, and nations. The results give readers and researchers new information about the development and growth of sports sensor technology subjects as well as about active and potential research areas. China is the most productive country, contributing 17 publications related to sports technology, while the United Kingdom is the most impactful country with 474 citations.

***Keywords**— Athlete Performance, sport technology, bibliometrics, co-word analysis, research trends*

1. INTRODUCTION

Over the last decade, technology has developed very rapidly. The industrial revolution 4.0, which was echoed at the Hannover Fair in April 2011, became the trigger for this development. Many studies have developed technology related to sports. Sport technology innovation aims to monitor developments and improve athlete performance. Advances in sports equipment technology have enabled athletes to set new standards for optimal performance [1]. The results of these sports technological innovations have had an impact on the progress of the sports industry itself. However, the impact of the development of sports technology can only be felt in developed countries [2].

The pertinent literature demonstrates that existing sports technology studies have carried out comprehensive reviews for innovation and entrepreneurship in football [3], Research on extended reality in sports: worldwide trends and hotspots [4], e-textiles for sports [5], and the use, validity, and reliability of Inertial Movement Units (IMU) in volleyball. However, no one has conducted a review of the use of sensor technology in sports performance. The emerging idea of integrating sensor technology in sports technology developments connected to sports performance can be better understood by further research of the existing literature using bibliometric tools.

The bibliometric analysis of research on sports technology and associated topics conducted between 2008 and 2023 is the primary contribution of this study. The study's results include an examination of the network of events that contain the author's chosen keywords related to sports technology, as well as the growth pattern of publications and citations, the most well-known papers, top authors, journals, institutions, and nations. Researchers and readers will be able to detect the development and expansion of sports technology subjects as well as identify current and future study fields thanks to these findings. The study's remaining sections are organized as follows: The research methodology is described in the next section. The third section is a description of the bibliometric study' findings. The research is finally concluded in the fourth section, which also includes suggestions for further research.

2. METHODS

We collected data on the Scopus database on June 17, 2023. Boolean logic functions, such as "AND" "OR" in Scopus, lead to the following search topics: (TITLE-ABS-KEY (sport) AND TITLE-ABS-KEY (technology) AND TITLE-ABS-KEY (sports AND performance)) AND PUBYEAR > 2007 AND PUBYEAR > 2007. This search returned 3,817 documents. Furthermore, we perform a more specific search string as follows: (TITLE-ABS-KEY (sport) AND TITLE-ABS-KEY (technology) AND TITLE-ABS-KEY (sports AND performance)) AND PUBYEAR > 2007 AND (LIMIT -TO (SUBAREA , "ENGI") OR LIMIT-TO (SUBAREA , "COMP")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (EXACTKEYWORD , "Athletic Performance") OR LIMIT- TO (EXACTKEYWORD , "Athletes") OR LIMIT-TO (EXACTKEYWORD , "Sports Performance")). This search resulted in 109 documents. The search and screening strategy can be seen in Figure 1.
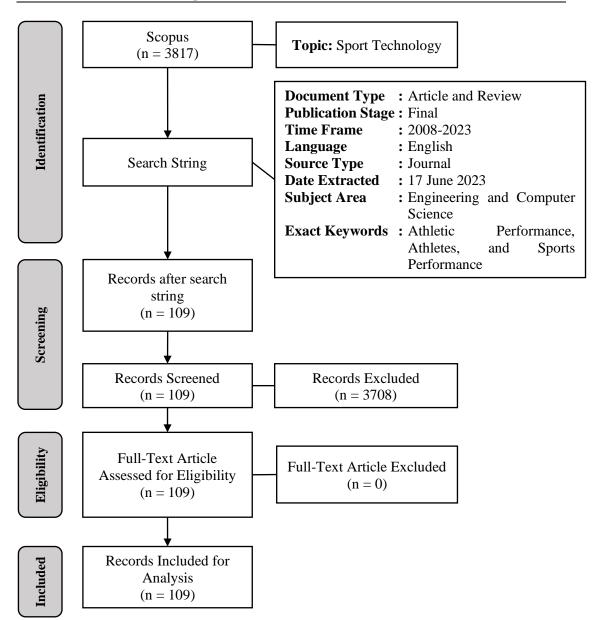
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Identification
    Scopus                    Topic: Sport Technology
   (n = 3817)

                             Document Type   : Article and Review
                             Publication Stage: Final
                             Time Frame      : 2008-2023
   Search String             Language        : English
                             Source Type     : Journal
                             Date Extracted  : 17 June 2023
                             Subject Area    : Engineering and Computer
                                               Science
                             Exact Keywords  : Athletic    Performance,
                                               Athletes,    and   Sports
                                               Performance
Screening
  Records after search
       string
     (n = 109)

  Records Screened          Records Excluded
    (n = 109)                 (n = 3708)

Eligibility
   Full-Text Article        Full-Text Article Excluded
  Assessed for Eligibility        (n = 0)
     (n = 109)

Included
  Records Included for
      Analysis
     (n = 109)
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Figure 1 PRISMA Flow Chart of Search and screening strategy
Note: Adapted from (Anandh et al., 2021; Gebre et al., 2021; Faulkner et al., 2022)

We made the decision to use Citation network analysis (CNA) as our primary method for analyzing current trends in sports technology research. A review method called CNA aims to map the scientific organization of a field of study in relation to citation patterns [9]. Microsoft Excel 16.63.1 (2021) is used to organize and preserve the forms of the retrieved metadata. VOSviewer 1.6.18 was employed in this study's bibliometric analysis. A well-liked tool for bibliometric analysis is VOSviewer [6]. With the use of bibliometric analysis, it is possible to keep track of the occurrences and trends of scientific publications related to a certain subject or field as well as the regular patterns of citation among the works [10]. Numerous bibliometric studies Internationally have used the free, widely used VOSviewer bibliometric analysis program [11]–[14] VOSviewer was developed by software engineers Van Eck and Waltman from Leiden University in the Netherlands [15]. One advantage of using VOSviewer for this purpose is that it can quickly assess the bibliometric data exported from the important journal archives, such as Scopus, Web of Science, and PubMed [10]. Furthermore, using the RStudio software, a theme

visualization is carried out based on the theme country and related issues. Similar visualizations were carried out in several previous studies with different themes [16]–[21].

3. RESULTS AND DISCUSSION

3.1. Publications Trends

From 2008 to 2023, researchers from 19 countries have published articles related to sports technology. The entire trend of publications on sports technology from 2008 to 2023 is depicted in Figure 2. Analysis based on the Scopus database shows that in 2009, only one article was published. In 2010, the number of articles published increased by four. On the other hand, between 2011 and 2014 there was a decline, namely in 2011 and 2012 there was 1 publication, then in 2013 and 2014 there were 0 publications. In 2015, there was an increase to five publications. In 2016, it decreased again to three publications. In 2017, there was an increase to 7 publications. In 2018, it decreased again to five publications. In 2019 and 2020, there was a significant increase to 14 publications. The increase occurred again in 2021, to 26 publications. In 2022, it will decrease to 22 publications. In July 2023, we found that there were already six publications. Thus, there will be a very significant increase in 2019 and 2021.
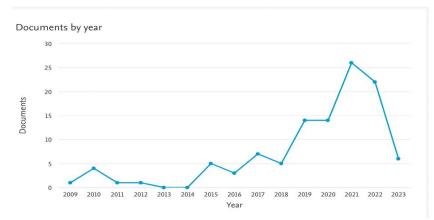

Figure 2 Annual Distribution of Total Publications

3.2. Authorship and Highest Citation

Figure 3 shows that among the 20 most prolific scholars, Baca and Kornfeind published their first paper on sports technology in 2010 and maintained steady results from then to 2022. Seshardi and Voos started publishing relevant papers relatively late in 2017, but they publish the most documents. For most scholars, once they start their research on sports technology, they will continue to publish papers, demonstrating the importance of research on sports technology.
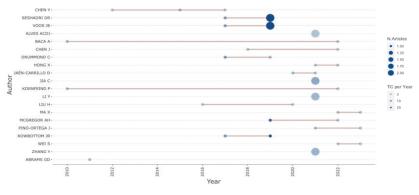

Figure 3 Authors' Production over Time

Table 1 shows the 10 authors with the most impactful articles on sports technology research. The first position is held by the article published by Bideau, with a total of 182 citations. The second position is held by the article published by Moris, with a total of 177 citations. The third position is held by an article published by Seshadri with a total of 128 citations. In fourth place is the article published by Adesida, with a total of 107 citations. Meanwhile, sequentially, the articles published by Fister, Peng, Seshadri, Ayachi, and Tabori have a total of less than 100 citations.

Table 1 Ten articles with the most citations based on Scopus

No	Document Title	Authors and Year	Citations Total
1.	"Using virtual reality to analyze sports performance [22]"	(Bideau et al., 2010)	182
2.	"Bio-sensing textile based patch with integrated optical detection system for sweat monitoring [23]"	(Morris et al., 2009)	177
3.	"Wearable sensors for monitoring the internal and external workload of the athlete [24]"	(Seshadri et al., 2019)	128
4.	"Exploring the role of wearable technology in sport kinematics and kinetics: A systematic review [25]"	(Adesida et al., 2019)	107
5.	"Planning the sports training sessions with the bat algorithm [26]"	(Fister et al., 2015)	98
6.	"Rational Design of Ultrasensitive Pressure Sensors by Tailoring Microscopic Features [27]"	(Peng et al., 2018)	90
7.	"Soft, skin-interfaced wearable systems for sports science and analytics [28]"	(Ray et al., 2019)	69
8.	"Wearable Devices for Sports: New Integrated Technologies Allow Coaches, Physicians, and Trainers to Better Understand the Physical Demands of Athletes in Real time [29]"	(Seshadri et al., 2017)	67
9.	"Identifying factors of bicycle comfort: An online survey with enthusiast cyclists [30]"	(Ayachi et al., 2015)	61
10.	"Sport biomechanics applications using inertial, force, and EMG sensors: A literature overview [31]"	(Taborri et al., 2020)	49

Figure 4 shows the annual distribution of total citations. In 2008, there were no citations related to sports technology. In 2009, there was only one quote. In 2010, there was an increase to 14 citations. In 2011, there was an increase to 19 citations. In 2012, there was an increase to 32 citations. In 2013, there was a decrease to 26 citations. In 2014, there was an increase of 41 citations. In 2015, there was an increase of 58 citations. In 2016, there was a decrease of 43 citations. In 2017, there was an increase to 56 citations. In 2018, there was an increase to 89 citations. In 2019, there was an increase to 122 citations. In 2020, there will be an increase to 206 citations. In 2021, there was an increase to 299 citations. In 2022, there will be an increase to 435 citations. In 2023, we found that there were already 208 citations. Annual changes can be seen in the total number of citations for sports technology research. The concept of research technology and research methodology is still in its infancy in the early stages of research. Consequently, there haven't been any papers of high caliber or significance in a while. This explains why there were so few citations overall from 2008 to 2013. In 2022, the total citations reached an all-time high, whereby sports technology-related papers published up to that year had already received as many as 435 citations. This shows that the research and development trend is increasing significantly.
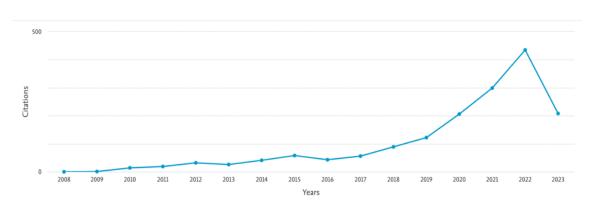
Figure 4 Annual Distribution of Total Citations

3.3. Distribution and Network Citation by Country

According to the quantity of citations to publications that have been published, Table 2 lists the top 10 nations. The country with the most citations is the United Kingdom, which has 474. Having received a total of 412 citations, the United States came in second. Australia ranked third with a total of 337 citations. Canada ranked fourth with a total of 150 citations. Meanwhile, Italy, Spain, China, the Netherlands, Portugal, and Brazil have a total of less than 100 citations. Governments in industrialized nations can support researchers working on sports technology with additional funding and data. The top four nations are developed nations as a result.

Table 2 Source: Scopus Database, Country Distribution by Citations, Documents, and Link Strength

Country	Citations	Documents	Total link strength
United Kingdom	474	11	14
United States	412	17	6
Australia	337	7	12
Canada	150	5	9
Italy	82	6	8
Spain	78	9	3
China	67	36	2
Netherlands	59	4	1
Portugal	28	5	4
Brazil	7	4	2

The distribution of article postings by nation is seen in Figure 5. Darker hues represent more articles that have been published. The majority of the pieces were released in China, the US, and the UK. The most publications were published by China, according to this statistic, yet there were only 67 total citations. However, even though there were fewer articles published in the United Kingdom, there were still 474 citations overall. This demonstrates that research trends and breakthroughs in the field of sports technology are significantly influenced by publications that are published in the United Kingdom.
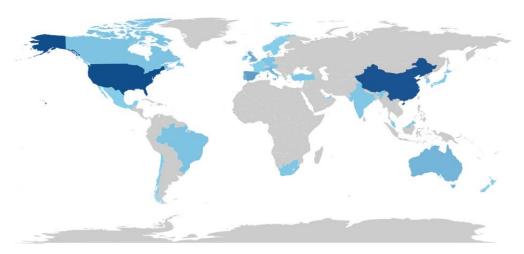
Figure 5 Country-based scientific production in the field of sports technology

There are three primary categories of cooperation networks: scholar-to-graduate, institution-to-institution, and country-to-country [14]. For this publication, we used the co-authorship feature in VOSviewer to get a collaboration network with a minimum of 1 document and 1 citation, which is displayed in Figure 6. The number of articles submitted from each nation is represented by the size of the nodes in the graph; cooperation between countries is represented by the lines; distinct groups are represented by the colors; and similarity of research topics is indicated by the distance between nodes. Our observations show that the cooperation network between countries in sports technology is divided into five clusters, with the main countries as follows: cluster #1, Canada, Germany, and India; cluster #2, Australia and Austria; cluster #3, China and United States; cluster #4, United Kingdom and Russian Federation; and cluster #5, Italy and Mexico.
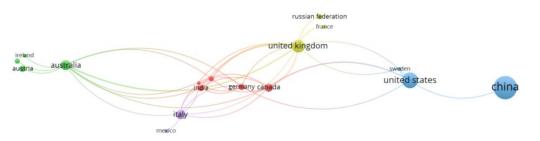

Figure 6 Network Visualization Citation by Country Source: Scopus database

3.4. Internal Characteristics of Publications

"Keywords can provide core information about the content of an article, and two or more keywords that appear in the same article at the same time are called co-occurrence keywords" [32]. In scientific knowledge fields, keyword co-occurrence analysis can be used to locate research hotspots and keep track of the movement of research borders [33], [34]. In this study, we created a keyword co-occurrence graph using the co-occurrence function in VOSviewer, which includes the fractional counting method, the minimum number of keyword occurrences set to 2, and author keywords as the unit of analysis. Each cluster has been grouped and is visible in Table 3 and Figure 7 of the grouping.
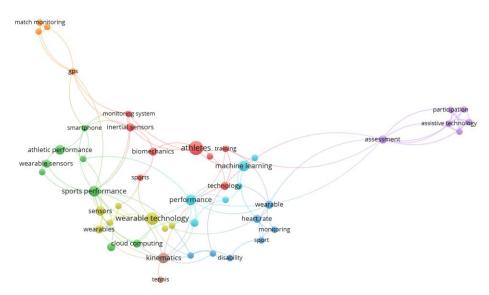
Figure 7 Network of co-occurrences for sport technology Author's Key Words Source: Utilizing Vosviewer, the author processed

Table 3 Network visualization and sport technology articles Source: Utilizing Vosviewer, the author processed

Cluster	Items	Colour	Percent-age	Total
Cluster 1	Artificial intelligence, football, performance, sensors, sports analytics, sports medicine, wearable technology, wearables.	Red	17%	8
Cluster 2	Disability, heart rate, IMU, monitoring, performance analysis, sport, wearable.	Green	15%	7
Cluster 3	Wearable, assistive technology, occupational therapy, parasport, participation, people with disabilities.	Blue	13%	6
Cluster 4	Athletic performance, body sensor network, smartphone, sports performance, sports technology, wearable sensors.	Light Green	13%	6
Cluster 5	Athletes, biomechanics, inertial sensors, speed, sports, technology	Purple	13%	6
Cluster 6	GPS, match monitoring, physical performance, team sport.	Light Blue	8%	4
Cluster 7	Machine learning, sport training, training load, wearable devices.	Orange	8%	4
Cluster 8	Cloud computing, data mining, feedback.	Brown	6%	3
Cluster 9	Monitoring system, training.	Pink	4%	2
Cluster 10	Kinematics, tennis	Light Pink	4%	2
Total			**100%**	**48**

Athlete performance, electronic gadgets, artificial intelligence, and wearable technology are all shown in the tree map in Figure 8; this illustrates how interdisciplinary sport technology is. Athletic performance is the primary study topic in sport technology, as evidenced by the fact that the phrase "athletic performance" appears in 10% of papers. Additionally, the terms "sports" and "athlete" are used in 9% and 5% of publications, respectively, showing that academics value these subjects highly while discussing sport technology. The terms "athletic performance" and "athlete" have emerged, demonstrating that enhancing athlete performance is the main objective of sport technology research.

Figure 8 Themes that Predominate in Sport Technology Studies RStudio was used by the author to process the data

When discussing the topic of sports technology, the words "athletic performance" and "sports" are the two most frequently used words (Figure 9). This demonstrates that the research topic of all papers about sports technology is athletic performance. Several other terms, such as artificial intelligence, sports performance, wearable electronic devices, and wearable sensors, which are crucial elements for the greatest advancement of sports technology, also refer to the focus of issues that are distinct from but connected to the primary subject under discussion. Later words might paint a different picture of how far sports technology development has progressed. It is intended that future scholars would draw attention to or concentrate on issues that have not received much attention thus far, giving them a good opportunity to thoroughly investigate these issues.

Figure 9 Major Sports Technology Issues RStudio was used by the author to process the data.

A sort of flow diagram is the Sankey diagram (Figure 10), often called the Sankey energy separation diagram. The top 10 three-field plots in the area of sports technology are shown in this figure, sorted by author, nation, and keywords. The United States, Portugal, the United Kingdom, and Australia produced the most content on "wearable technology," which was the most popular

topic overall. In contrast, "censorship" received the least amount of contributions from three nations: the United States, Portugal, and Brazil.
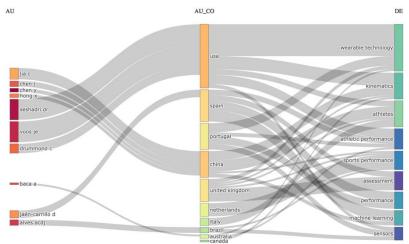

Figure 10 Three-Field Plot by Author, Country, and Keywords

4. CONCLUSIONS

The field of sensor-based athlete performance measurement technology research in sports technology has experienced exponential growth in the last 10 years, between 2008 and 2023. This study reveals patterns of growth in publications and citations, authors, and countries, which offer potential implications for researchers and practitioners. China is the most productive country, contributing 17 publications related to sports technology, while the United Kingdom is the most impactful country with 474 citations. With regard to athlete performance measuring technologies in sports technology, which are fostering the development of this sector, this information can assist researchers in their search for partnerships, research direction, and expert opinion. Network analysis of the author's keyword list sheds light on the development and growth of the subject, indicates active and future study areas, and aids in its growth. Sports technology is a topic with great potential for academics and practitioners, with the collaboration of academics from various fields contributing to the development of this field.

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