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ABSTRACT

The swift development in the field of artificial intelligence, solid states electronics and nanotechnologies has been the driving force in the innovative designs of Unmanned Underwater Vehicles (UUVs). Based on this, the need for bibliometric analysis of the influential articles, journals, universities/institutes, countries and authors has become paramount. Therefore, 548 publications related to Unmanned Underwater Vehicles were extracted from the web of science that spans over the period 1986 to 2019. The results indicate a steady rise in the yearly UUV research publications with 2018 having the highest (54), but 2019 is still counting. A total of 1383 authors published the entire articles with Caccia M having the highest number of UUV publications of 28 articles which is 5.109% of the total.

Keywords: Unmanned underwater, Bibliometric, Web of science, Vosviewer.Author Correspondence, e-mail: ayshermuhd@gmail.comdoi: <http://dx.doi.org/10.4314/jfas.v12i1S.19>

1. INTRODUCTION

There are abundant types of aquatic resources (minerals and halobios) in oceans and seas, some of which are yet to be explored. As a result, new devices and tools with so many strategies for sea explorations are being investigated. The unmanned Underwater Vehicles (UUV) was first initiated to acquire knowledge and control of the undersea battlespace with the use of off-board sensing unit [1]. They are reliable to operate, unoccupied and widely used for activities that are difficult to be handled by a human. UUVs have the capability of performing the task as well as exchanging information with terminal stations or ships. For research, examining, operation of the facilities under the water or getting details of seas as well as life-forms, UUVs are typically utilized. UUVs can be majorly categorized into three types for carrying out various missions under certain conditions namely [2-5]: Remote Operated Underwater Vehicles (ROV), Autonomous Underwater Vehicles (AUV) and Autonomous Underwater gliders (AUGs). ROVs can navigate within a small range of location, depending on the size and versatility. This restricted motion is as a result of their hard-tethered to surface support vessel characteristics [6]. However, AUVs are much more adaptable as they are more appropriate for long-range survey missions, and are at the same time able to cater for challenging operations that are quite expensive to achieve in navigations systems [5]. UUVs are widely employed in various practical applications; as such, there is a need for improvement in some strategies used (power supply, navigation technique, control) [7-11]. They have become increasingly popular and attract so much attention for their applications in ship maintenance, ocean study, the survey of mineral resource and hydrographical as well as applications in the military sector [12,13]. The advancement in UUVs started with a study on the theoretical design (shape and form) and analysis on the operational, power requirement as well as propulsion capabilities [14]. These are achieved by considering the UUVs' ability to navigate with low drag [15] while maintaining its operational performance by finding the UUVs' propulsion systems [16]. To find a suitable power supply, the endurance limit is taken into consideration to determine the proper sizing [17].

Bibliometric is the analytical evaluation which examines bibliometric features and also information such as publications, citations, as well as research study results. [18-21]. It

permits researchers to recognize research activities, framework, qualities, and patterns. The evaluation process correlates the study activities into a reasonable trend of a research domain, as it includes scientific research works of various contexts such as publications, institutions, authors, organizations countries, and also citations. It is an approach that reports on the thorough analysis of the growth of research areas [22,23].

This paper performs an analysis of the unmanned underwater vehicles documents published in the Web of Science from 1986 to 2019. The method includes the evaluation of publications, research subjects and countries. In order to achieve this study, the following questions were created: (1) what is the pattern of publications and (2) exactly how does this pattern assist in recognizing the future direction of UUVs. Using " Unmanned Underwater Vehicles " as the primary keyword phrase, we recognized over 548 articles. All these are entirely taken from the Web of Science Core Collection. With the chosen articles, an analysis was carried out to establish the connection between the publication, title, abstract, keywords, research topic, citation, and location.

2. MATERIALS AND METHODS

2.1 Methods

Bibliometric analysis initially introduced by Alan Pritchard [24] is a methodical approach to quantitatively assess research literature in order to determine and identify the research patterns. Research progress in different field of study can be measured using a bibliometric study [25]. The distribution patterns of article publication time, publishing journals, authors and research topics are evaluated using bibliometric analysis. Information extracted from the database such as Web of Science, Scopus and Google scholar is usually processed using HistCites or BibExcel tools [26]. A visualization tool known as Citespace developed by Chen Chaomei's group is used for evaluating and analyzing research literature in order to determine their knowledge intellectual landscape domain. Authors, collaborating countries, cited papers and keywords can be obtained through the refinement of different types of nodes in CiteSpace application [24].

In this research, VoSviewer application is employed. Authors, countries, articles and institutions were used as nodes to analyze the study partnership network. Using circular nodes,

cited authors, collaborating between authors and countries were used to evaluate the intellectual research structure. Authors keywords were also used to evaluate the research study pattern.

2.2 Data Source

Numerous databases are used to index articles among which are Web of Science (WOS), Elsevier's Scopus, Science Direct, IEEE Explore, Springer Google Scholar, and ACM (Association for Computing Machinery). However, the top major database used for bibliometric analysis is WOS, Elsevier's Scopus and Google Scholar [27–29]. Bibliometric analysis has been extensively performed by researchers using the ISI Web of Science (WOS), which is one of the top accessible journal citation database offered by Thomson Reuters [30]. It is one of the most globally acknowledged and used scholastic database because of its consistency and simplicity in extracting data (journals, authors details, and citation references) [31]. It is therefore worthy of mentioning that this study is limited only to the WOS database, which can be seen as the limitation or scope of the study. As earlier mentioned, the search phrase used was “Unmanned Underwater Vehicles” and based on the search, 548 documents were extracted on 01/10/2019 from the database which falls between the year 1986 to 2019. Conference proceedings articles were included in the analysis in order to increase the number of data.

3. RESULT AND DISCUSSION

3.1 Chronological distribution

Based on the WoS database, the first “Unmanned Underwater Vehicle” document was published in the year 1986 by Pritzlaff [32]. Figure 1 shows the chronological distribution of the publication. Before the year of 1998, the numbers of annual publications were not more than 10, with no between the years 1986 to 1990. All these signify less research interest or limited knowledge sharing at that time. A sudden fluctuation in the publication number occurs between the late 90s to 2005, indicating an unsteady interest in the research field. From 2005 upward, there has been a steady increase in the number of publication outputs which is possibly due to the technological developments in the electronic world.

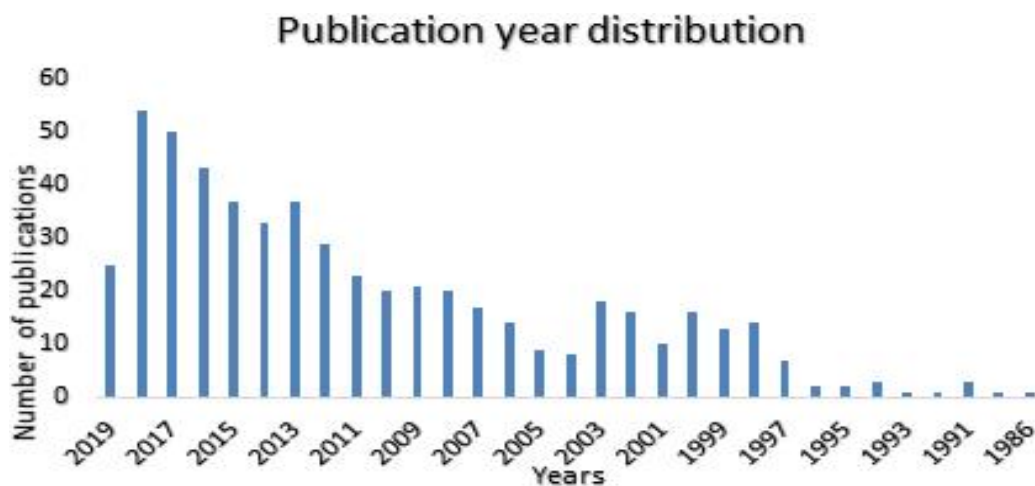


Fig.1. Publication distribution

3.2. Analysis of Journals

The 548 UUV related articles were published in 401 WoS index journals. Based on the data collected, out of the 401 journals, 306 journals published only one research article within 33 years. Table 1 shows the leading six most active journals with the exclusion of all conference proceedings. The six journals amount to 19.86% of the entire UUV articles.

Oceans IEEE is the most active journal with a total of 54 published articles, representing 9.747% of the overall publications. The second most active journal is the IEEE Journal of Oceanic Engineering with 18 articles, making up 3.249% of all the publications. Ocean Engineering is the third most productive journal with 14 articles amounting to 2.89%. The remaining three are Sensors, Control Engineering Practice and IEEE Access with 1.44%, 1.26% and 1.26% respectively.

Table 1. Top 6 Publishing sources

Journal	Records
Oceans IEEE	54
IEEE Journal of Oceanic Engineering	18
Ocean Engineering	16
Sensors	8
Control Engineering Practice	7
IEEE Access	7

3.3 Authorship analysis

A total of 1383 authors published UUV related articles with an average of 3 authors per article. Table 2 shows the top 9 authors with the highest number of published UUV articles. It is found that Caccia M. is the most active author with 28 documents, followed by Veruggio G. with 24 papers and the third Yan ZP with 18 papers. The remaining authors are listed in the table with their corresponding records.

It is of paramount importance to assess and analyzed the citation and co-citation link between UUV researchers. Hence, figure 2 shows the author's citation visualization network for the extracted data using VOSviewer. There is a total of 548 articles which if plotted the nodes and interconnections will not be visible, as such a threshold is set where only articles with five citations and above are eligible for display. Based on that, 52 articles were selected and are categorized into 12 clusters. Each article is represented in the form of a circular node represent. The node size indicates the significance of an article within a cluster as well as the entire network. The line density indicated the citation strength both within a cluster and the neighbouring clusters (reflecting by the number of their co- citers). Articles and clusters situated close to each other signify the strong bond in terms of content. Cluster #1 is denoted by the Green colour and contains eight related UUV research articles. It appears almost all the articles come from Caccia M. Cluster #2 contains seven documents and is denoted by the Red colour. The cluster contains articles from the same author that is dominant in cluster #1, which is basically why the two clusters a located very close to each other happens to have the most dominant article in the cluster. Cluster #3 is in deep blue and contains six articles with Negahdaripour being the dominant author. Cluster #4 has five items and is denoted by Yellow colour. It is at the center of the clusters indicating how relevant it is in the UUV research. Healey has the dominant article which was published in 1993. Below is the list of dominant articles from the top six clusters.

1. Multivariable sliding mode control for autonomous diving and steering of unmanned underwater vehicles [33].
2. Modelling and identification of open-frame variable configuration unmanned underwater vehicles [34].
3. A review of developments towards biologically inspired propulsion systems for

autonomous underwater vehicles [35].

4. Fault detection of actuator faults in unmanned underwater vehicles [36].
5. Dynamical sliding mode control for the trajectory tracking of underactuated unmanned underwater vehicles [37].
6. An ROV Stereo Vision System for Ship-Hull Inspection [38].

Table 2. Topmost active authors with publications more than.

Authors	Records	% of 548
Caccia M	28	5.109
Veruggio G	24	4.38
Yan ZP	18	3.285
Bruzzone G	15	2.737
Zhu DQ	14	2.555
Bono R	9	1.642
Sun B	9	1.642
Kim J	8	1.46
Lee PM	7	1.277
Sutton R	7	1.277
Carreras M	6	1.095
Conte G	6	1.095
Eren F	6	1.095
Lane DM	6	1.095
Pe'eri S	6	1.095
Wang M	6	1.095
Xu J	6	1.095
Zhou JJ	6	1.095

These articles are written and published by the researchers among the top 10 publishing authors and journals, respectively. However, article citation analysis can be biased as some authors might have some preliminaries included in their names or have various shortened names, or various names (e.g., names altered due to marital relationship) [39]. Therefore, it is essential to develop a unique identification for every author to prevent such mistakes [40].

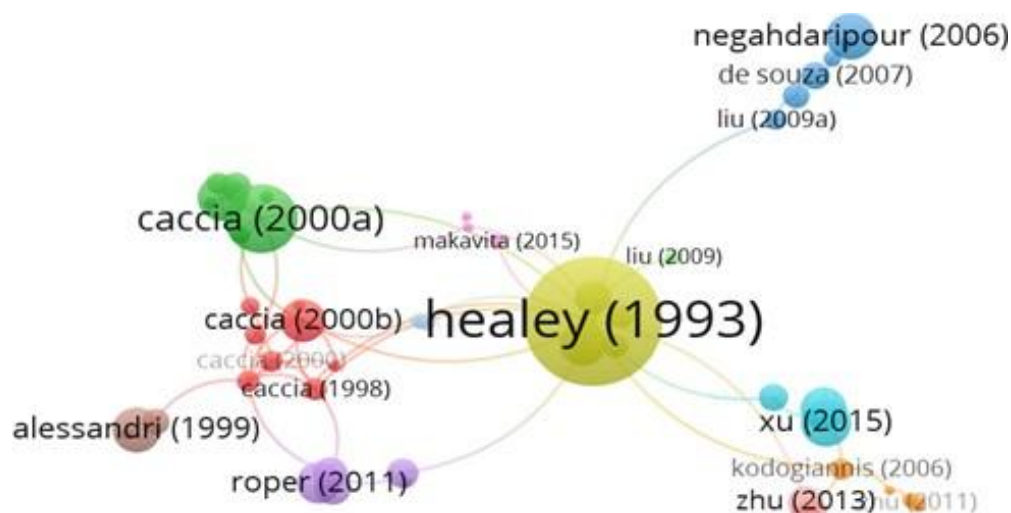


Fig.2. Article citation network

3.4. Countries

The country collaboration network of the published articles under the topic unmanned underwater vehicles is presented in figure 3. The node size and lines are represented by the number of documents in each country and the collaboration between them. The publishing countries can be seen to be group into about 8 clusters. Certainly, international researchers publishing more on the topic are from the USA, China and Italy indicated by more astronomical cycles (purple, blue and red respectively).

Table 3. Top 10 Countries.

Countries/Regions	records
USA	185
Peoples R China	93
Italy	55
South Korea	35
England	28
Australia	16
Canada	16
Norway	14
Scotland	14
Spain	13
Russia	12
Japan	11

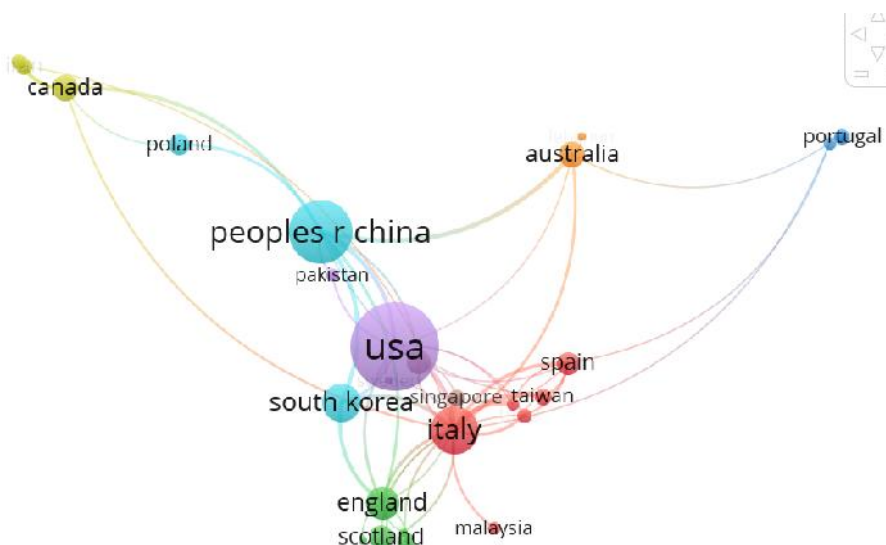


Fig.3. Publishing countries network

3.5 Research trend

To determine the top research topic and reveal the research study trend, the author’s keyword over a particular time span is used. The top 50 keyword phrases were selected to perform the analysis. Unmanned underwater vehicle is the first and the highest citation keyword phrase. It appeared first in the 1986 paper written by Pritzlaff [32] and was published in the IEEE Journal of Oceanic Engineering. Within the eight displayed clusters illustrated in figure 4, the underwater vehicle is the second largest keyword after unmanned underwater vehicles.

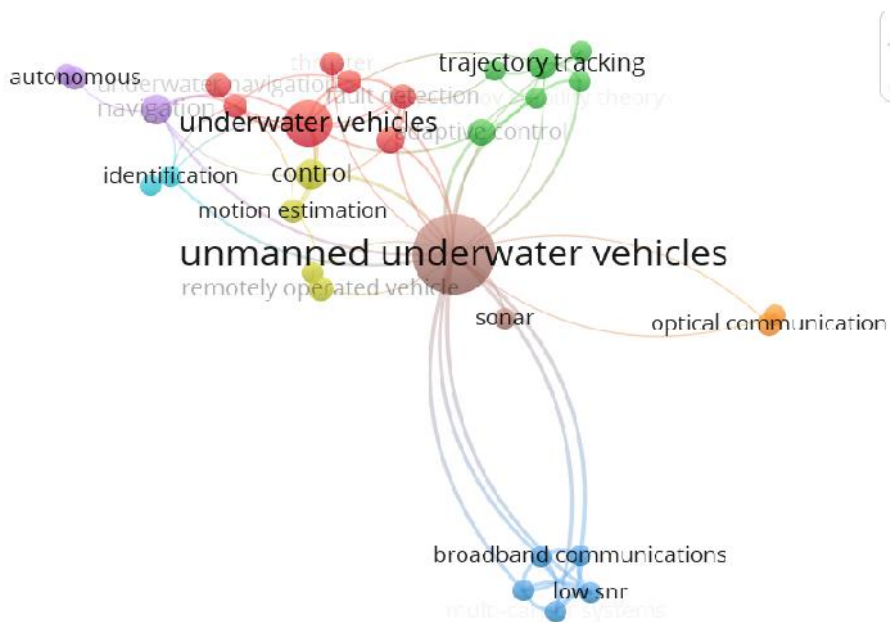


Fig.4. Authors keyword network

4. CONCLUSION

It can be reported that research interest in the field of UUV is rising, which is why the number of published articles has been increasing yearly. In order to summarize the study progress and also propose future directions of unmanned vehicle research, this study presents a bibliometric analysis on articles extracted using the search phrase “Unmanned Underwater Vehicle” published in 33 years (1986-2019) in the Web of Science database. Research outcome reveals that 584 articles were published within the period. As indicated by the yearly output, there was less UUV research interest at the beginning, but later on, around the late '90s there was a swift rise in the global research interest in the UUV field. All the articles were published in 401 journals, showing a diversification in the publication. Oceans IEEE, IEEE Journal of Oceanic Engineering and Proceedings of SPIE were the top three journals publishing UUV related articles. In total, 1383 authors were those that authored the 584 published articles. The top 3 most cited articles were [33-35]. It can be deduced that collaboration in the research field is weak as researchers tend to work together within a smaller cluster, this could probably be due to the cost of equipment as well as the sensitivity of the research field. Authors keyword analysis was performed to track the top topics and reflect on the research study pattern.

It is recommended in the future study to conduct similar analysis using a different database such as the Scopus. Moreover, an additional search phrase can be included in order to broaden the search and include more research articles, therefore having enough data for analysis.

As a whole, this research study provides beneficial insights and future research instructions on UUVs study to ensure that researchers in this area can better identify the active authors, institutions and organisations, countries that have enough resources, interest and expertise in the UUV research field.

5. ACKNOWLEDGEMENTS

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