MADRID
inter.noise 2019
June 16 - 19
NOISE CONTROL FOR A BETTER ENVIRONMENT

Exploring the roles of artificial intelligence and next-generation virtual technologies in soundscape studies

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ABSTRACT

Soundscape is an acoustic environment experienced and/or perceived by people, in context. As soundscape is a dynamic environment that each person experiences and perceives it differently, we witnessed a surge of research studies using virtual reality technologies to expose people to different soundscape designs for visualization and auralization. These studies help us understand how people may experience, perceive, and characterize sonic environment differently in the same context or different contexts. As the representations of soundscape are numerous, artificial intelligence and machine learning can be utilized to learn and optimize soundscape characteristics for making a better environmental design. This paper reviews and discusses the roles of virtual reality technologies and artificial intelligence in soundscape studies and designs.

Keywords: Soundscape, Virtual reality, Artificial intelligence
I-INCE Classification of Subject Number: 61

1. INTRODUCTION

Although the word ‘soundscape’ can be traced back to over a century ago, it was primarily used by musicians and painters to portray different aspects of natural and/or man-made sounds before the 1960s [1]. In 1967, Southworth [2] in his Master of City Planning’s thesis entitled – The Sonic Environment of Cities explored the perceptual form of the soundscape and established techniques and language for recording soundscape, very similar to the so-called soundwalks and soundmarks in today’s soundscape-related field studies [3]. At about the same time, a Canadian composer and music educator, R. Murray Schafer, wrote the book entitled – The New Soundscape: A Handbook for the Modern Music Teacher in which he challenged his students to broaden their view on the sonic environment surrounding them [4]. Schafer [4] illustrated that as societies and technologies evolve, humans experience different sonic environments (see Table 1).

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Table 1. Soundscape as a function of time in human history

Period	Types of Sounds		
	Natural Sounds	Human Sounds	Sounds of Tools and Technology
Primitive period [1]	69%	26%	5%
Medieval, renaissance & pre-industrial period [1]	34%	52%	14%
Post-industrial period [1]	9%	25%	66%
Modern period - 1960s [1]	6%	26%	68%
- now [2]	<1%	<20%	>79%

Notes: [1] The values were adopted from Schafer [4]; [2] The values were estimated by the authors who have studied environmental noise in a highly urbanized city such as Hong Kong [5].

Subsequently, Schafer and his fellow researchers initiated the project – the World Soundscape Project. The World Soundscape Project initially focused on the characterization of sonic features in Vancouver and was then extended to a number of villages and cities in Europe [6,7]. Schafer in his book – The Soundscape: Our Sonic Environment and the Tuning of the World suggested that a soundscape can be any acoustic field of study [8; p.7] and consists of events heard not objects seen [8; p.8]. Soundscape studies encompass nature, science, society, and even the arts. Depending on the situation, people can be exposed to sounds emitted from anthrophonic sources such as vehicles, trade activities, mechanical equipment, etc., biophonic sources such as dogs, birds, insects, etc., and geophonic sources such as rain, wind, thunder, etc. [9]. Recently, the International Organization for Standardization [10] harmonizes the definition of soundscape and defines soundscape as the "acoustic environment as perceived or experienced and/or understood by a person or people, in context".

As time passes by, researchers and town planners are not only interested in characterizing soundscape, but also the projected change in soundscape due to the interactions between humans and their surroundings. Because of the complexity of soundscape and soundscape design, many researchers and town planners start using virtual reality as a way to visually and aurally construct three-dimensional spaces in which users may immerse themselves in different sonic environments [11-14]. Moreover, users may express their feelings toward a particular soundscape very differently due to their own experiences, emotions, sensibilities, cognitive abilities, interpretations and cultures [15,16]. In order to come up with a better soundscape design, artificial intelligence can be utilized because it is able to give relevant recommendations based on deep learning from soundscape-related data sets. Nevertheless, how many researches have been conducted in the areas of 'soundscape and virtual reality' and 'soundscape and artificial intelligence' have yet to be known. Additionally, research frontiers of 'soundscape and virtual reality' and 'soundscape and artificial intelligence' are kept evolving. Thus, the objectives of the paper are (i) to determine the number of publications i.e. researches that have been published about 'soundscape and virtual reality', 'soundscape and artificial intelligence', and 'soundscape, virtual reality, and artificial intelligence' in the past decades, and (ii) to identify what research frontiers/emerging topics we may focus in the near future.

2. METHOD

To meet the objectives of the study, we conducted a review of the extant academic literature about 'soundscape and virtual reality', 'soundscape and artificial intelligence', and 'soundscape, virtual reality, and artificial intelligence'. The three commonly used academic databases in scientometric and bibliometric studies are Web of Science, Scopus, and Google Scholar [17-19]. At the time of writing this paper, Web of Science Core Collection covers over 20,000 journals, 190,000 conference proceedings, and 90,000 editorially selected books and has about 71 million records from these sources [20]. Scopus covers over 23,700 journals, 8.3 million conference papers, 166,000 books, etc. and has about 71 million items from these sources [21]. Google Scholar does not indicate how many journals and conference proceedings it covers but it has over 380 million records [22]. Moreover, past researches [23,24] demonstrated that Scopus has a broader coverage than Web of Science for recent publications across all disciplines of science. Additionally, Web of Science and Scopus have a set of strict journal and conference inclusion/exclusion criteria focusing on peer-reviewed journal and conference articles while Google Scholar covers peer-reviewed articles as well as articles from non-peer reviewed repositories and sources [23,25]. Thus, we used Scopus as the source database in the present study.

To identify the publications about 'soundscape and virtual reality', we entered 'soundscape' to the search term and selected 'Article title, Abstract, Keywords' as the search field plus 'virtual reality' to another search term and 'Article title, Abstract, Keywords' as the search field. Figure 1 shows an image clip as we conducted our study on 3 January 2019. Similarly, we used 'soundscape' AND 'artificial intelligence', and 'soundscape' AND 'virtual intelligence' AND 'artificial intelligence' for the second and third searches.

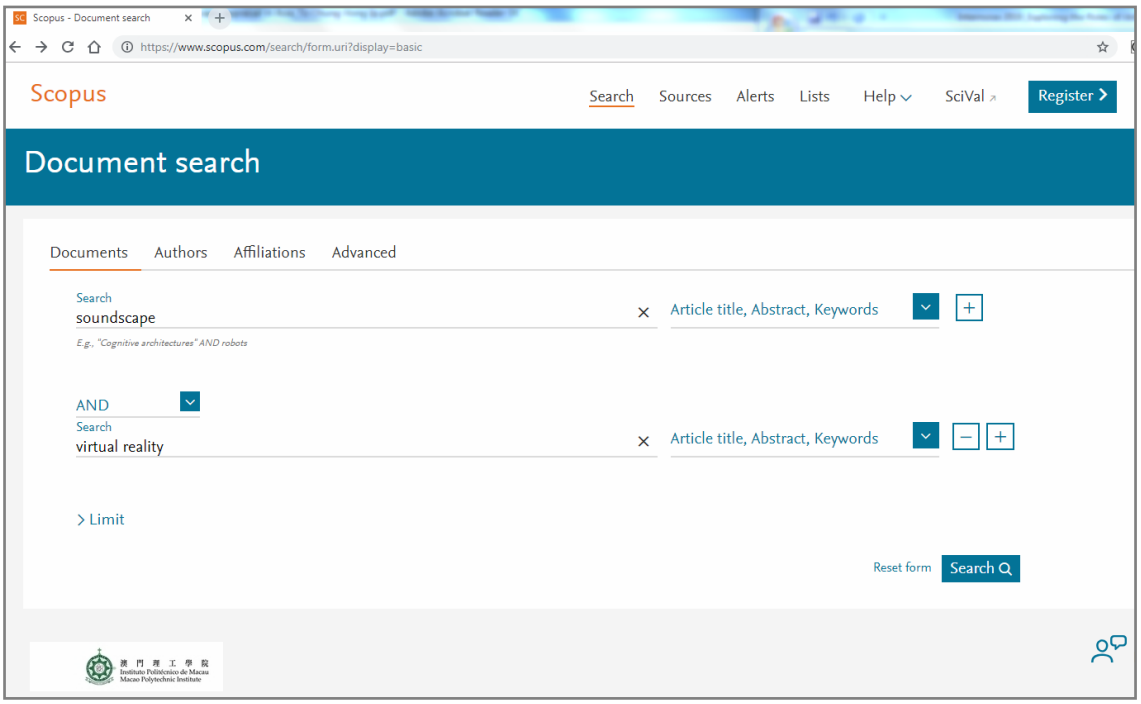

Figure 1. Document search using Scopus

3. RESULTS AND ANALYSIS

3.1 Soundscape and Virtual Reality

After searching "soundscape' AND 'virtual reality' using Scopus, the search results showed that there were 130 items based on the criterion - (TITLE-ABS-KEY (soundscape) AND TITLE-ABS-KEY (virtual AND reality)). Five items were deleted because they were conference reviews (with no author). Among the 125 selected items, there were 89 conference papers, 32 journal papers, 3 book chapters, and 1 review paper. Figure 2(a) shows the number of publications in the past decades. It indicated that 3 papers were published before the Year 2000, 32 papers between 2000 and 2010, and 90 papers from 2010 to present. Figure 2(b) shows the number of publications by author. Prof. Luigi Maffei of Universita della Campania Luigi Vanvitelli in Italy was ranked first with 11 publications, followed by Prof. Michael Cohen of the University of Aizu in Japan. Figure 2(c) shows the number of publications by country/territory. It was found that researchers in Japan produced 18 publications and U.S. researchers also produced the same number of publications, followed by 14 from Italian researchers. As soundscape and virtual reality researches are multi-disciplinary in nature, 67 of the 125 papers were categorized as 'Computer Science', 43 papers in 'Engineering', 37 papers in 'Physics and Astronomy', 19 papers in 'Mathematics', and 13 papers in 'Social Sciences' as shown in Figure 2(d).

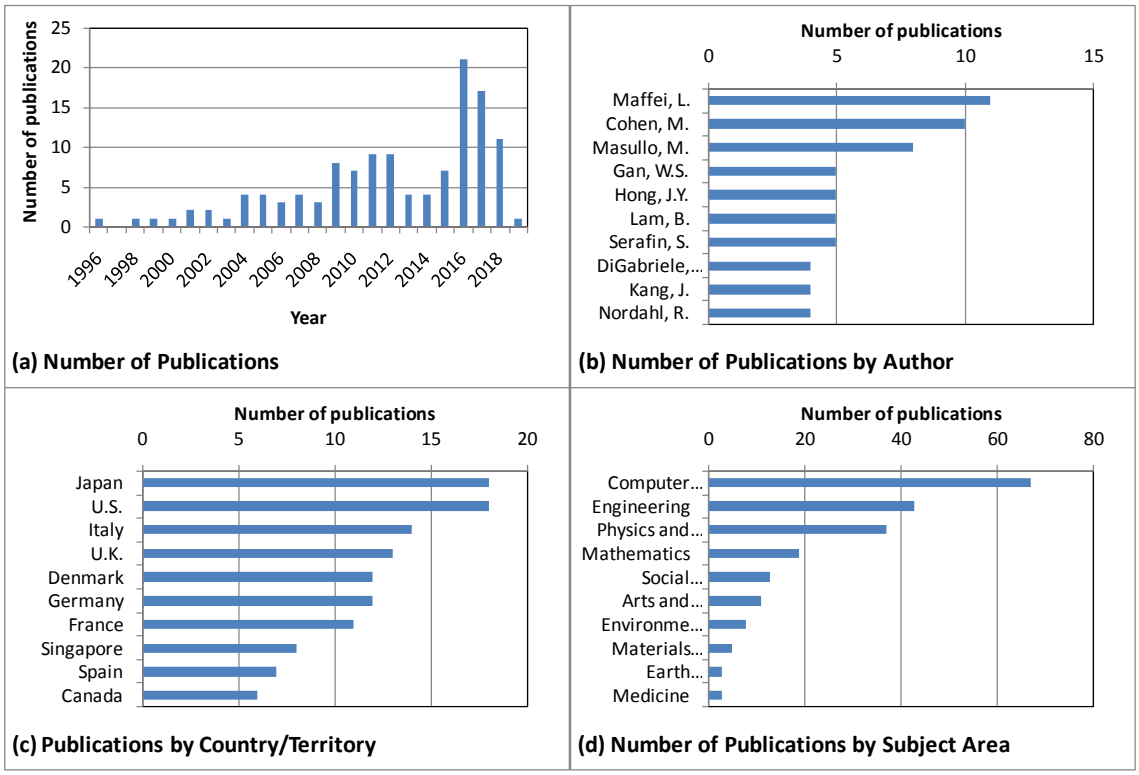

Figure 2(a) the number of publications during the period 1996 to present i.e. January 2019; (b) the number of publications by author; (c) the number of publications by country/territory; and (d) the number of publications by subject area.

We selected all the 125 records with full details and exported them to RIS and CSV (excel format) files. We used VOSviewer (www.vosviewer.com/) to visualize the co-authorship network of authors [26-28]. We set the minimum number of publications to be '3' and 26 authors met such a criterion. Five clusters of co-authorship were identified including Maffei's group in Italy, Cohen's group in Japan, Gan's group in Singapore, Serafin's group in Demark, and Amemiya's group in Japan as shown in Figure 3. When we analyzed the records using the co-occurrence of keywords (set the

minimum number of occurrence of keywords to be ‘3’), 97 keywords met such a criterion. Figure 4 shows that seven clusters were identified. The green colored one shows ‘virtual reality’ having strong connections with ‘augmented reality’, ‘human computer interaction’, and ‘virtual environments’. The red colored one shows that although ‘soundscape’ has a strong connection with ‘virtual reality’ (GREEN), ‘soundscape’ is also closely associated with ‘acoustic noise’, ‘noise pollution’, and ‘spatial audio’. The blue colored one shows ‘virtual reality’ to be associated with ‘groupware’, ‘internet’, and ‘networked appliance’. The purple colored one shows ‘virtual reality’ to be associated with ‘surveys’, ‘head mounted displays’, ‘loudspeakers’, and ‘sound designs’. The light blue colored one shows virtual reality to be associated with ‘perception’, ‘sensory perception’, ‘physical model’, and ‘audio-haptic’. The yellowish green colored one shows virtual reality to be associated with ‘human’, ‘navigation’, ‘walking’, ‘cognition’, and ‘sound’. Finally, the light brown color one demonstrates ‘virtual reality’ to be associated with ‘soundscape’ and ‘computer music’.

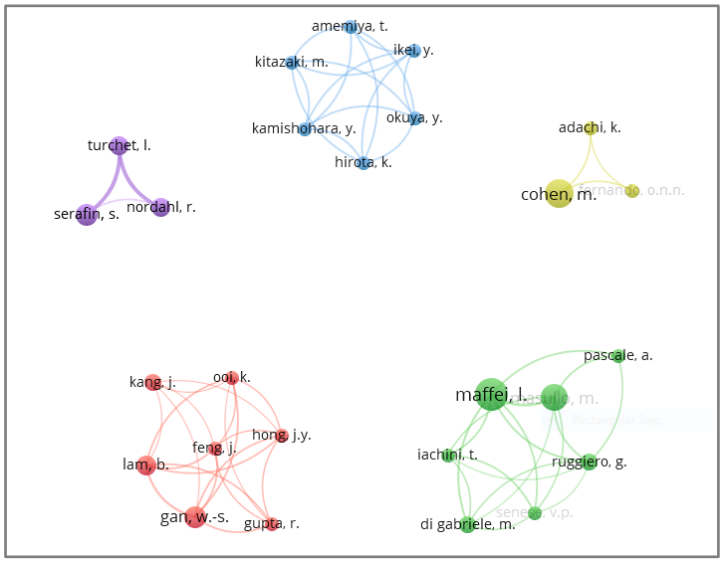

Figure 3. Co-authorship of articles about ‘soundscape and virtual reality’

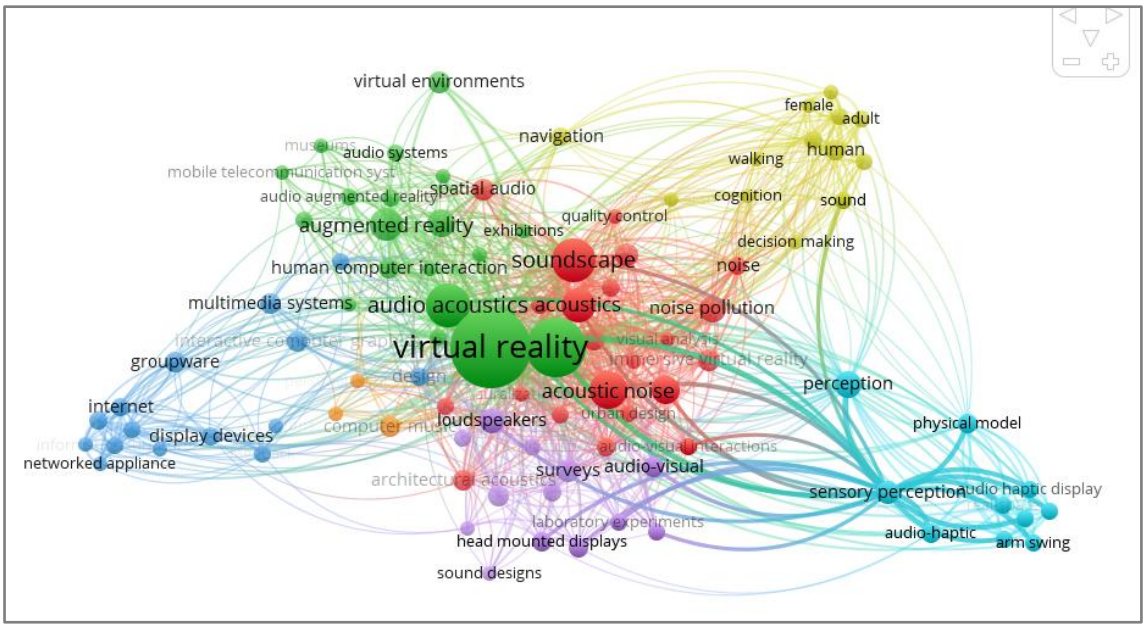

Figure 4. Co-occurrence of article keywords

3.2 Soundscape and Artificial Intelligence

When ‘‘soundscape’ AND ‘artificial intelligence’ was searched using Scopus, the results showed that 26 items were found based on the criterion - (TITLE-ABS-KEY (soundscape) AND TITLE-ABS-KEY (artificial AND intelligence)). Among the 26 items, 20 of them were conference papers and 6 of them were journal papers. Figure 5(a) shows the number of publications in the past decades. It indicated that no paper was published before the Year 2000, 4 papers between 2000 and 2010, and 22 papers from 2010 to present. Figure 5(b) shows the number of publications by author. It showed that even the most productive authors have published two papers on this topic in the past decade(s). Figure 5(c) shows the number of publications by country/territory. It was found that researchers in France produced 6 papers, followed by researchers in Japan producing 4 papers. As soundscape and artificial intelligence researches are multi-disciplinary, 15 of the 26 papers were categorized as ‘Computer Science’, 8 in ‘Physics and Astronomy’, 5 papers in ‘Engineering’, and 3 papers in ‘Mathematics’ as shown in Figure 5(d).

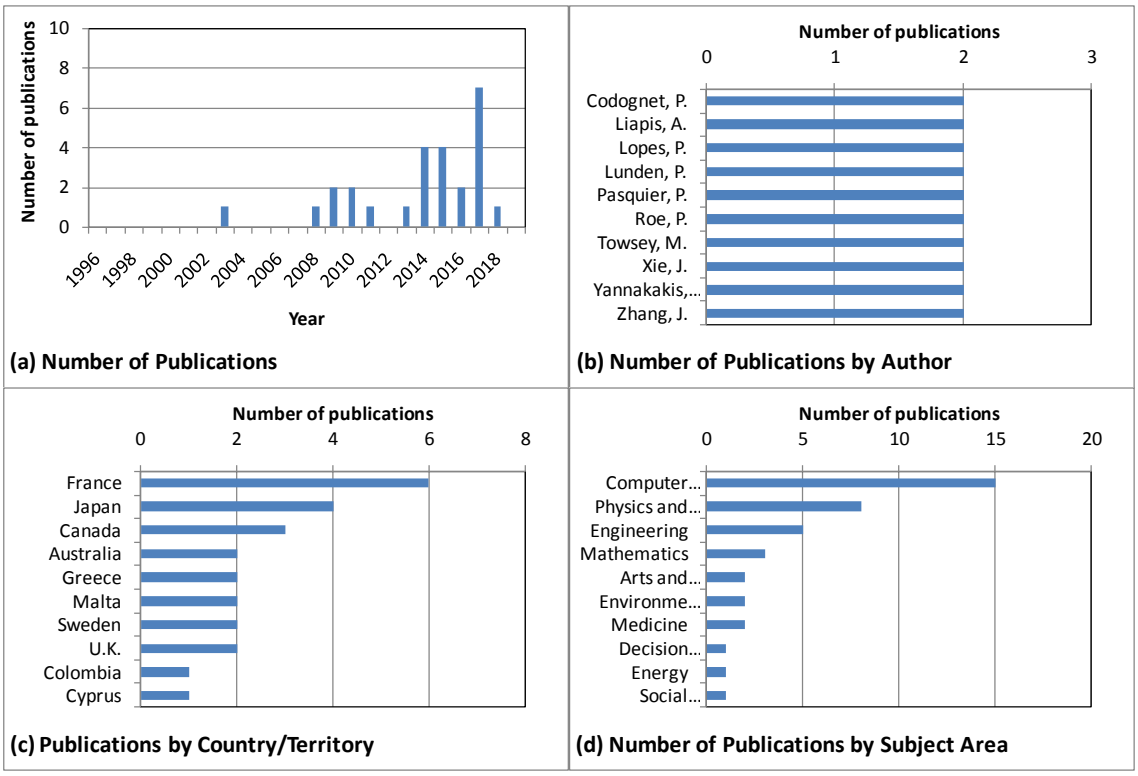

Figure 5(a) the number of publications during the period 1996 to present i.e. January 2019; (b) the number of publications by author; (c) the number of publications by country/territory; and (d) the number of publications by subject area.

We selected all the 26 records with full details and exported them to RIS and CSV (excel format) files. We used VOSviewer (www.vosviewer.com/) to visualize the associations of keywords. We did not visualize co-authorship because all authors either published one or two papers. We analyzed the records using the co-occurrence of keywords and set the minimum number of occurrence of keywords to be ‘2’ (because only 26 papers were studied), 43 keywords met such a criterion. Figure 6 shows that five clusters were identified. The red colored one shows ‘artificial intelligence’ to be linked to ‘learning systems’, then to ‘learning algorithms’, ‘soundscape ecology’, ‘feature extraction’, and ‘acoustic feature extraction’. The green colored one shows

'artificial intelligence' to be linked to 'acoustic noise', then to 'machine learning', 'noise pollution', and 'environmental management'. The purple colored one shows 'virtual reality' having strong connections with 'soundscape', 'computer science', and 'human computer interaction'. The blue colored one shows 'soundscapes' to be associated with 'artificial life', 'computer-based music', 'media arts' and 'autonomous agents'. The yellow one shows 'artificial intelligence' to be linked to 'optimization', then to 'classification', 'algorithms', and 'support vector machines.

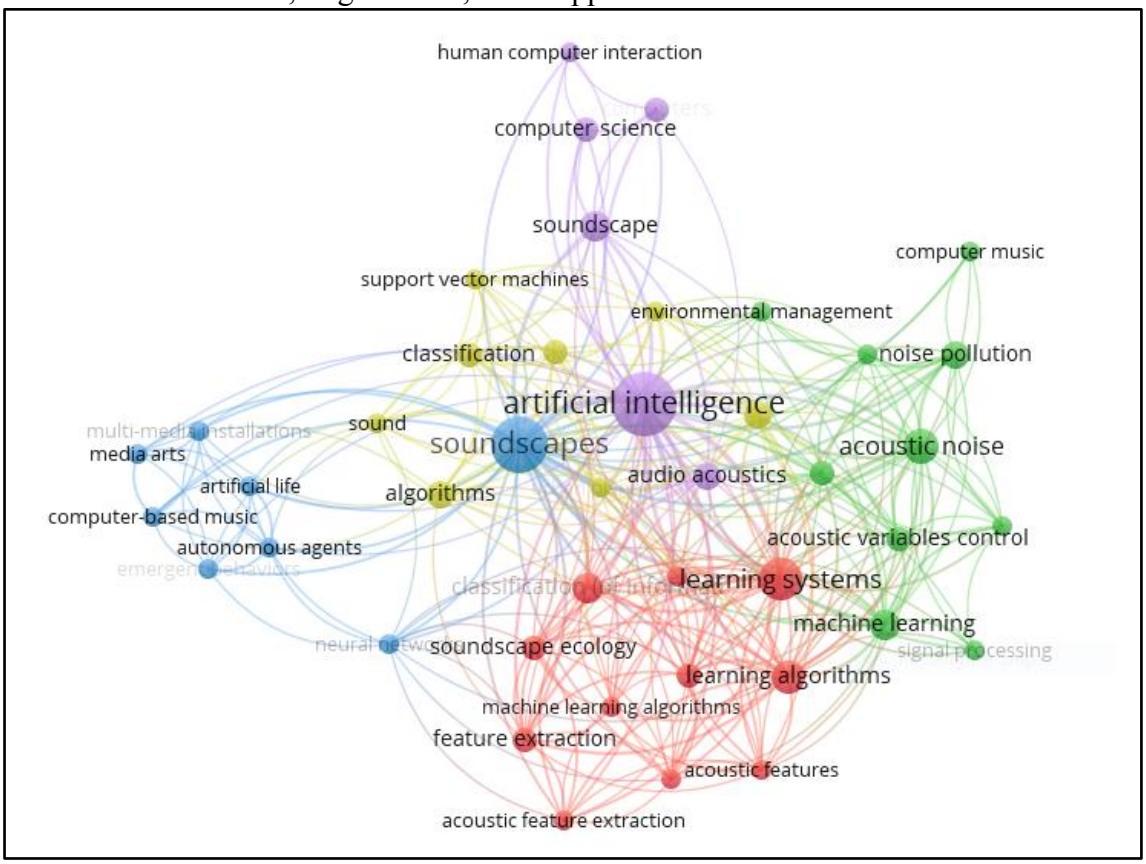

Figure 6. Co-occurrence of article keywords

3.3 Soundscape, Virtual Reality, and Artificial Intelligence

When "'soundscape' AND 'virtual reality' AND 'artificial intelligence'" was searched using Scopus, the results showed that no document was found based on the criterion - (TITLE-ABS-KEY (soundscape) AND TITLE-ABS-KEY (virtual AND reality) AND TITLE-ABS-KEY (artificial AND intelligence)).

4. DISCUSSION AND CONCLUSIONS

Soundscape is an evolving topic of great relevance to people's life. It is because no matter where we go, we are exposed to sounds from a wide range of natural and anthropogenic sources. Soundscape studies are important to scientists, engineers, sociologists, and urban planners because they allow scientists and engineers to understand the nature of soundscape, sociologists to understand how humans respond to different sonic environments, and urban planners to identify what constitutes good (or bad) soundscapes. Moreover, people are always looking for better environments. Hence, the number of publications i.e. researches on applying virtual reality/artificial intelligence to soundscape studies has increased over the past decades. Using Scopus as the source of peer-reviewed papers, we identified that there were 125 papers on 'soundscape AND virtual reality' and 26 papers on 'soundscape AND artificial

intelligence'. A citation analysis showed that researcher groups in Japan, Italy, Singapore, and Denmark are very actively engaging in conducting 'soundscape AND virtual reality' researches, particularly focusing on urban designs, environmental sounds, and the sense of immersion and interactivity by research groups in Italy, Singapore, and Denmark, and on groupware, soundscape stabilization, network appliance, and haptic interface by research group in Japan. For 'soundscape AND artificial intelligence', no researcher group has produced more than two papers in this topic. Yet, researchers in France, Japan, and Canada in total produced 11 peer-reviewed papers among the identified 26 papers. Their recent publications focused on learning algorithms, acoustic feature extractions, soundscape ecology, and classifications.

The present study shows the complexity of soundscape studies because they involve human perceptions in different contexts. Virtual reality technologies are good ways to expose human subjects to different sonic environments. As human responses are subjective in nature, they cannot be easily quantified precisely. Yet, people are good at comparison, especially in a continuous match, and are able to reach consensus. Hence, crowdsourcing people's sonic identification and applying content analysis to qualitative big data – a subtopic of artificial intelligence and machine learning – can be a possible research direction in solving such complex problems.

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