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About dynamics of publication activity on synchronization

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Abstract. *Purpose* of the work is to research of the world science publications dynamics on the synchronization. *Methods*. The research methods are the statistical methods of data processing. *Results*. The emphasis in the study of synchronization over the past twenty years has shifted from physical and technical sciences to neuroscience with Asian countries domination.

Keywords: synchronization.

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Introduction

Three or four decades ago, the objects of studying nonlinear dynamics were mainly physical and technical objects. At the present stage of development, the objects of its study are extremely complex dynamic systems and processes from biological, chemical, social, economic, and other applications. The behavior of such systems in phase space is determined not only by limit cycles and tori, but also by strange chaotic attractors and metastable states. Understanding the dynamics of complex systems relies on the key processes of nonlinear dynamics — competition and synchronization [1, 2].

Over the years, synchronization theory has made a giant leap in its development from the classical synchronization of two self-oscillating oscillators [3] to the synchronization of networks of

chaotic oscillators [4–6]. Today, synchronization theory is a theory of synchronization of oscillator networks, which has great applied significance (communication networks, computer networks, power grids, networks of connected robots, ecological networks, neural networks, nanosystems, quantum networks, etc.) [7]. The theory of synchronization of oscillator networks, in particular, controlled synchronization, is still far from complete. In very popular simple mathematical models of ensembles of Kuramoto oscillators, new synchronization patterns have been discovered, in particular, «chimeric» states (coexistence of synchronicity and asynchrony) [8]. Discovery of chimeras in the science of synchronization, it suggests the existence of a huge number of new forms of synchronization that can be very interesting for applications (stabilization of synchronization of power grids, new forms of communication and encryption, cognition of brain work, etc.).

Thus, it can be stated that the phenomenon of synchronization is now of interest in a variety of sciences. Publications related to the study of various aspects of synchronization theory can now be found in a huge number of scientific journals of various profiles. However, it should be noted that when analyzing publications, publications where the term «synchronization» is used incorrectly or erroneously in a sense different from that accepted in physics (for example, when describing synchronicity, synchronism, that is, the simultaneity of events). It is appropriate to raise the question — is it possible, without making a detailed analysis of articles on synchronization, to get some, at least the most general information about the dynamics of the development of this topic, based on publication statistics? Below is an attempt to find an answer to this question.

1. Analysis of publication activity by synchronization

Topics related to synchronization issues are widely represented in domestic and foreign publications. You can try to identify some trends in the development of this topic by analyzing the simplest indicator — the number of publications. The results of the analysis of English-language scientific journal literature using the computer database Science Citation Index Expanded (SCIE) are presented below. Almost all the world's magazine publications are represented in this database. Choosing the search topic set by using a certain template, you can search by article titles, keywords and annotations. Such a search does not include the full text of the article, so it is impossible to estimate the full number of publications on the selected topic with such a search. Nevertheless, such a search allows us to determine the qualitative trends in the number of publications on the topic and the dynamics of their changes over the period under review.

It should be noted that the SCIE database (as, indeed, other computer databases) is not immutable, but is constantly being updated, in particular, in connection with the digitization of new materials. Until the 1990s, the database included only the titles of articles, and from the 1990s until about the 2000s, it was actively replenished with data on keywords and annotations of articles. Therefore, the most reliable information can be extracted from the analysis of the data contained in the database since the 2000s.

The results of the experiments are presented below. In Fig. 1, *a* shows a diagram reflecting the number of publications by year. It was obtained as a result of a search containing the «synchro» template in the search topic, in Fig. 1, *b* — template «synchron», and in Fig. 1, *c* — word «synchronization». The search was carried out by the titles of articles, by keywords and by annotations. Naturally, the diagram Fig. 1, *c* showed the smallest number of publications, since the search for the word «synchronization» filtered out articles that are not related to the phenomenon of synchronization (with words related to the simultaneity of events: synchronizm, synchronizer, synchronous and others, as well as synchroscope, synchronoscope, synchrophasotron et al). It should be noted that qualitatively the diagrams in all three figures are the same, that

is, if you are not interested in accurate quantitative data, then you can use the diagrams of all three figures to interpret the results , although Fig. 1, *c* with word search «synchronization» is preferable because it displays more reliable digital data. From the diagrams Fig. 1 the undoubted growth of the number is obvious publications on synchronization in the last two decades. The growth of the topic of synchronization can be explained as follows: in all disciplines where the old static models are replaced by dynamic ones, concepts also penetrate «oscillations», «synchronization», for example, biology is no longer a descriptive science for a long time and deals with oscillatory models, synchronization models at different levels - ensemble, molecular, cellular, etc., etc. In this connection, it is interesting to look at the distribution of publications on the topic «synchronization» in journals of various scientific fields.

The distribution of publications in journals of various scientific profiles is shown in Fig. 2. The search was carried out according to the «synchron AND oscil» template, taking into account the titles of articles, keywords and annotations. Fig. 2, *a* presents the results for 1975–1990, Fig.. 2, *b* — for 1990–2021 . Diagrams Fig.. 2 demonstrate an obvious shift of interest in the topic «synchronization» from physical and technical sciences to biological and neuroscience. In the interval of 1975–1990 . electronics is leading, and since 1990 — this is already neuroscience.

Of course, the diffusion of the term "synchronization"from the traditional physical and technical sciences for this term into many others (biology, medicine, mathematics, etc.), apparently, can be considered as the main reason for the steady increase in the number of publications on synchronization noted above. Along with this, there may be other reasons for the increase in the number of publications, for example, reasons related to the development of the term «synchronization» when it diffusion into different sciences, expansion and even some blurring of the concept of «synchronization». So in the 1980s, in connection with the discovery of dynamic chaos, a new direction in synchronization theory arose, dealing with the synchronization of chaotic oscillations [4–6], which caused a noticeable number of publications on the synchronization of chaotic oscillations and an increase in the total number of publications on synchronization. On Fig. 3, *a* shows diagrams reflecting the number of publications on the synchronization of chaotic oscillations. The search was carried out by the titles of articles, keywords and annotations, the search topic included pattern «synchron AND chaos». In Fig. 3 *(b)*, the ratio of the number of works on synchronization of chaotic oscillations to the total number of works on synchronization is presented. Obviously, the contribution of chaotic synchronization (about 4%) is quite significant.

A similar analysis can be carried out with respect to neurosynchronization. Synchronization

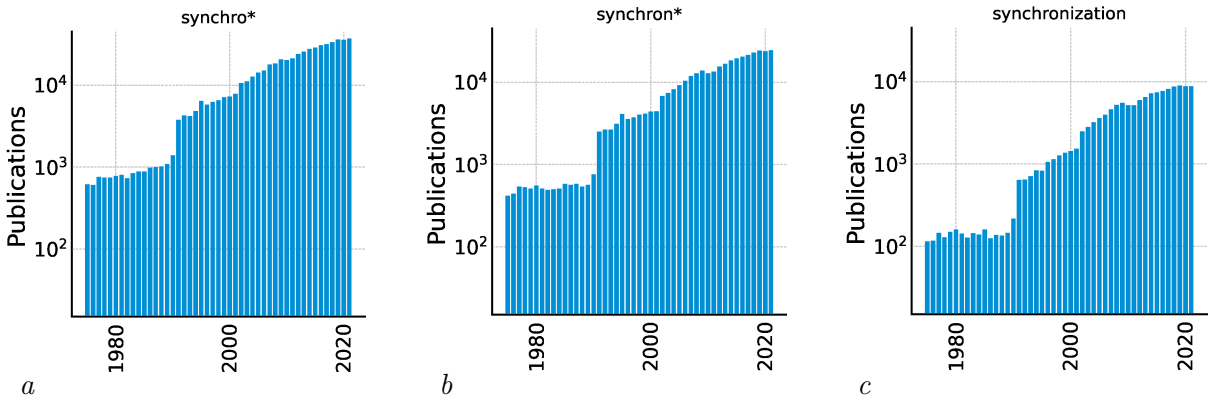


Fig. 1. The number of publications when searching by template «synchro» (*a*), «synchron» (*b*), «synchronization» (*c*)

in neuroscience has been intensively engaged since about the 2000s. In Fig. 3 *c* diagrams reflecting the number of publications on synchronization in neuroscience are presented. The search was carried out taking into account the titles of articles, keywords and annotations according to the template «synchronization AND neuro». From the diagrams in Fig. 3 *c* it is obvious that the number of publications on synchronization in neuroscience is now very significant and it is growing quite fast.

2. Analysis of publication activity on the topic: phase-locked loop (PLL)

Let's analyze the development of another branch of synchronization theory, which is important in an applied sense, related to automatic synchronization systems, in particular, with phase synchronization systems (phase locked loop, PLL). In the second half of the last century, the theory of such systems was actively developed in relation to the study of both dynamic properties and statistical [9–11]. These systems have found wide application in radio engineering, radio communications, radar, radio navigation, etc., which stimulated a large number of publications on the theory of automatic synchronization systems.

In Fig. 4 diagrams reflecting the number of publications on phase synchronization systems are presented. The «phase locked loop (PLL)» template was used in the search topic. In Fig. 4, *a* the results of the search by article titles are shown in Fig. 4, *b* — by keywords, and in Fig. 4, *c* — by annotations. In the 2000s, there was a noticeable increase in publications on this topic. Most likely, it can be explain the spread of interest in the theory of such systems in non-traditional areas for phase-locked loop systems (journals in computational physics, applied mathematics, biophysics, etc.).

In Fig. 5 diagrams are given showing the distribution of publications on phase-locked loop systems by country and year. The charts provide data on the top ten most actively published

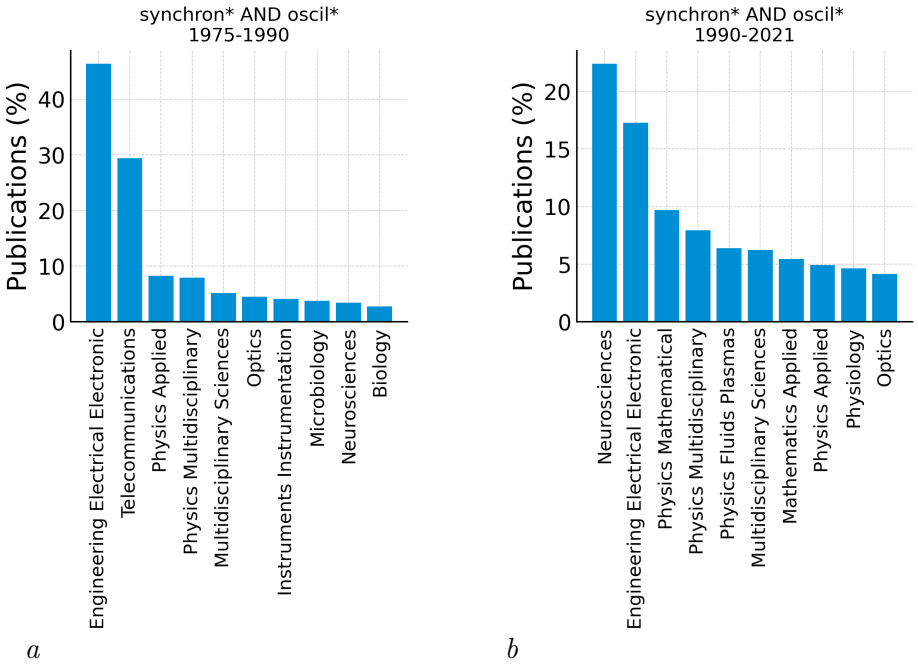


Fig. 2. Distribution of publications in journals of different profiles for 1975–1990 (*a*), 1990–2021 (*b*)

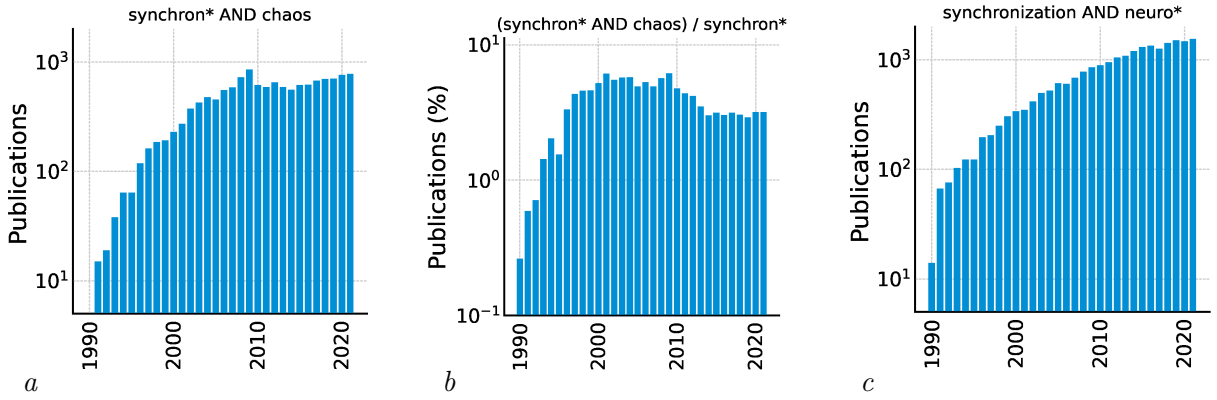


Fig. 3. The number of publications on synchronization of chaos oscillations (a). The ratio of the number of publications on chaos synchronization to the total number of publications on synchronization (b). The number of publications on synchronization in neurosciences (c)

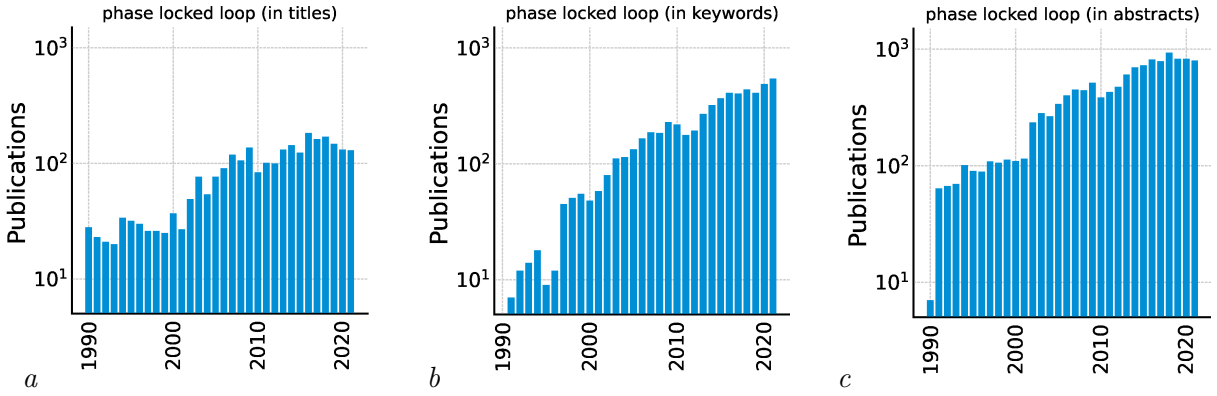


Fig. 4. The number of publications on phase locked loop, when searching by titles (a), by key words (b), by abstracts (c)

countries. The search was carried out by the names of articles. From these diagrams it follows that in 1975–1990 the largest number of publications were carried out from the USA, which is not surprising, since the topic of phase synchronization systems is typical for technically developed countries. In 1990–2005 the dominance of the United States also remained, but China and Russia entered the top ten in English-language publications, which were not in the top ten in the previous period. As for 2005–2021 , China's dominance is unequivocal in publications here.

In Fig. 6, a a diagram is presented showing the number of publications on phase-locked loop systems when searching for all indicators — article titles, keywords and annotations, and in

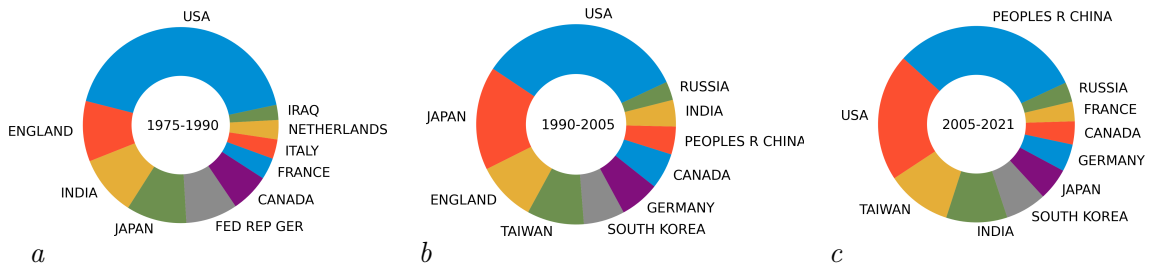
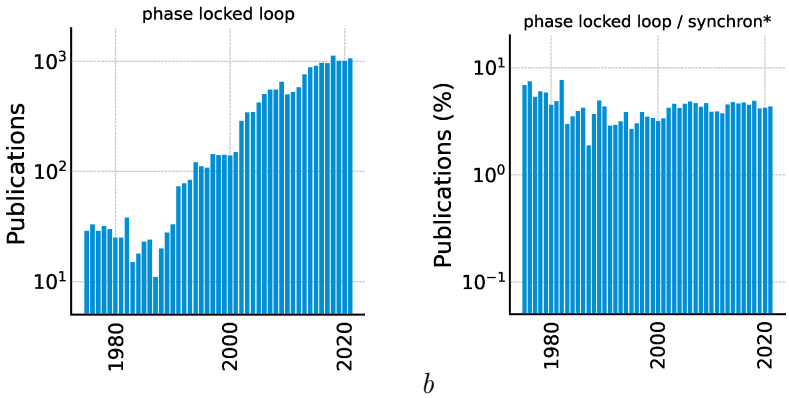


Fig. 5. Distribution of publications on phase locked loop by country of the world (the top-ten countries) for 1975–1990 (a), 1990–2005 (b), 2005–2021 (c) (color online)



a *b*

Fig. 6. The number of publications on phase locked loop (*a*), the ratio of the publications on phase locked loop to the total number of publications on synchronization (*b*)

Fig. 6, *b* a diagram is given showing the percentage ratio of the number of publications on phase-locked loop systems (search by template «phase locked loop») to the total number of publications by synchronization (search by template «synchron»). It is interesting to note that despite the general increase in the number of publications on phase-locked loop systems and synchronization in general, the percentage of the number of publications on phase-locked loop systems to the total number of publications on synchronization remains approximately constant over the entire time interval under consideration — about 4%.

3. Forecast capability

The obtained diagrams indicate that since the 1990s there has been a fairly active growth in the number of English-language publications in the world journal literature on various aspects of synchronization. The question arises about the possibility of forecasting changes in the number of publications for the upcoming period of time. Constant changes in the conditions for the development of world science entail constant changes in publication activity, mostly unpredictable, as a result of which it is enough to build a plausible forecast of the dynamics of publication activity for a sufficiently long period of time according to the data obtained is not possible.

However, for a short period of time in the absence of significant changes in the development of science, we can try to make an appropriate forecast. Suppose there is a hypothetical dynamic system whose behavior is described by the variable x — the number of publications on some branch of science (for a certain time, for example, for five years). Assuming the previous value is x_n fully defines the following (after five years) the value of x_{n+1}, we can consider the mapping of the shift along the trajectory determined by this dynamic system and construct a sequence function $x_{n+1} = F(x_n)$ [12]. In Fig. 7 such a sequence function is constructed based on the data of Fig. 1, *c*. If we connect the obtained points of a continuous curve, it is easy to see that in the time interval 2010–2020 the constructed function the sequence is located above the bisector, however, approximating the location of the sequence function near the value 42000, it is easy to see that the curve tends to cross the bisector, forming a stable fixed point, which allows us to assume that in the future the coordinate x will not exceed the predicted value corresponding to the fixed point.

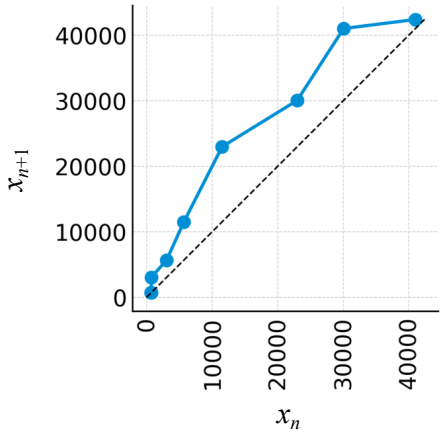


Fig. 7. The sequence function

Conclusion

Now various computer databases have become quite widespread. In this note, using the example of using one of these databases, it is shown that it is possible to extract useful information about the dynamics of the development of specific sections of sciences of interest to the researcher, based on only one indicator - the number of publications.

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