Studies of Dynamic Processes

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Abstract. The traditional approach to experimental data processing is based on the estimation of the averaged characteristics of the process, such as mean, variance, and range. However, a deeper processing with the identification of the features of the non-wicked dynamic behavior of the process allows us to see those features that are very important for a more complete understanding of its essence. The article provides examples of identifying the features of the dynamic behavior of processes in the atmosphere, studying the dynamics of heat and mass transfer when air moves in the upper respiratory tract of a person, and acoustic vibrations excited by a flame in the environment. Using the example of processing the time series of fluctuations in atmospheric air temperature, it is shown what unexpected information can be hidden in dynamic changes.

1. Introduction

Often, when processing the results of experiments, some averaged characteristics of the process are estimated, such as the average value, variance and range. However, a deeper processing with the identification of the features of the dynamic behavior of the process allows you to see those features that are very important for a more complete understanding of its essence. The following are examples of identifying the features of the dynamic behavior of processes in some studies.

Examples include:
- Processing of the values of the time series of observations of the average daily values of air temperature for 80 years;
- Heat and mass transfer in a living organism, where the connection of such processes with manifestations of various pathologies and the possibility of their quantitative description was revealed;
- In the research of the combustion process;

In [1], it was shown that there is a clear and unambiguous relationship between the pathologies of the upper respiratory tract and the spectral power density of temperature and pressure fluctuations of the air flow during its passage through the respiratory tract. It also presents the results of numerical 3D modeling of the air passage process in parallel with the field experiments carried out on solid 3D models, as well as the results of nonlinear dynamic modeling of breathing processes. This made it possible to solve some practical problems, for example, to memorize chaotic oscillations in a compressed form, in the form of several coefficients of a nonlinear dynamic model.

Why dynamical methods?

The answer to this question can be illustrated with the example of fluctuations in ambient air temperature.
2. Studies of dynamic processes. Fluctuations in ambient air temperature

There are a number of observations from the average daily air temperature values $x(t)$ for 80 years (figure 1, left.). What can be seen in this time series? Mean, range, and standard deviation only? Here, the average temperature is mean $(x) = 4.84 \degree C$, standard deviation $\text{std} (x) = 10.23 \degree C$; and fluctuation range, also range $(x) = 62 \degree C$. It is clearly visible harmonic temperature oscillations with a period of about 365 days (figure 1, right), but daily oscillations at first glance look like a chaotic noise process.

![Figure 1](image)

**Figure 1.** Average daily air temperature values $x(t)$ for 80 years. General view on the left, part of the graph is highlighted on the right.

Data processing will begin with an analysis of the power spectral density (PSD) of oscillations. Diagram PSD depending on the frequency of the process, expressed in units of $(1/\text{day})$ is shown in figure 2.

![Figure 2](image)

**Figure 2.** Power spectral density (PSD) of average daily air temperature values $x(t)$ oscillations for 80 years.

Taking into account the calculation error, the following were obtained:

1. The period of solar activity is $T = 11.22$ years.
2. The period of the Earth’s revolution around the Sun $T = 372$ days.
3. Quarter of the year (spring, summer, autumn, winter). $T = 91$ days
4. The duration of the lunar month is $T = 31$ days.

All this information is simply hidden in the dynamics of air temperature changes!

We will consider temperature fluctuations as a deterministic chaotic process. Now, let's use another trick for more information. First, let's move on to the so-called “reconstructed phase space” based on the “Takens time delay embedding theorem”, in which axes of coordinates are formed by shift of copies of the studied variable concerning themselves for a certain time delays $\tau$ and the following information is deposited along the coordinate axes:

1. Original time series;
2. A copy of the original time series is shifted relative to the original by time $\tau$;
3. The copy of the original time series is shifted relative to the original by $2\tau$;
4. …etc.

The application of the time delays to the average daily temperatures is illustrated in figure 3.

![Figure 3](image_url)

**Figure 3.** Application of the time delays to the average daily temperatures. Delay $\tau$ on the left is $\tau = 7$ days, in the center $\tau = 91$ days and on the right $\tau = 1022$ days.

In figure 3 on the left is applied a delay of a quarter of the lunar month $\tau = 7$ days. If there were no regularity and periodicity in the oscillations, instead of compact "turns" there would be a "ball of tangled wire". Further Fig. 3 in the center, a delay $\tau = 91$ days is used, which is about a quarter of a year. And in Fig. 3, on the right, the delay is $\tau = 1022$ days, which corresponds to a quarter of the sunspot change period, about 11 years.

The above figures refer to the so-called strange attractors and their analysis allows one to obtain additional information about the process under study, for example, the attractor dimension, embedding dimension and the Kolmogorov entropy. Unfortunately, the volume of the article does not allow considering the given example in more detail.

3. Human breathing processes

For this, miniature sensors are used, which are located on the nasal septum and introduce minimal distortions in the characteristics of the moving air stream [1]. The sensors measure flow characteristics such as temperature, pressure and velocity. An optoelectronic sensor was also used to measure CO2 pulsations during breathing [1].

The transducer is attached to a clip (figure 4) that attaches to the nasal septum. The photo shows a pressure take-off tube and a miniature temperature sensor.

![Figure 4](image_url)

**Figure 4.** Clip with pressure taps and temperature sensor. The photo shows the tube to pressure drain and miniature temperature sensor.

Figure 5 shows the fluctuations in air temperature in the nostrils during breathing and the spectral power density of temperature fluctuations, and figure 6 shows the reconstructed attractors in three-dimensional phase space for temperature fluctuations in the nostril. For a healthy person at the top and for asthma patients at the bottom.
Figure 5. Fluctuations in air temperature in the nostrils during breathing (left), and the spectral power density of the oscillations (right).

Figure 6. Reconstructed attractors in three-dimensional phase space for temperature fluctuations in the nostril. On the left is the attraction of a healthy person, on the right is an asthma patient.

4. Flame research
The sensor system for research of combustion processes was built on the basis of acoustic sensors and was tested on flames, while the dynamic characteristics of the flame were analyzed (Fig. 7).

Figure 7. Experimental setup (a), signals from sensors (b), spectral power densities of signals (c), reconstructed attractor (d). Sampling rate 13 kHz, time delay for the reconstructed attractor $\tau = 232 \mu s$.

5. Conclusions
For a more complete identification of the information contained in the observation results, it is necessary to carry out processing with the identification of the features of the dynamic behavior of the process. This allows you to see its implicit features. The examples examined have illustrated these provisions.

6. References
[1] Lukyanov G N et al. 2017 Technical Physics, IET 62(3) pp 484-489