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ANALYSIS OF THE FRACTAL CHARACTERISTICS OF HYDRODYNAMICAL STREAMS

Abstract*. Laminar and turbulent hydrodynamic flows are analyzed on the base of fractal image processing techniques. Fractal dimensions of images of hydro-dynamic streams were calculated with the help of techniques of classic and modified Box Counting, a comparative analysis of the results. Empirical distributions of local fractal dimensions and fractal cestrum were built.*

Keywords*: hydrodynamic stream, fractal dimension, self-similar structure, fractal cestrum (signature), the empirical distribution of the local fractal dimensions*

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АНАЛИЗ ФРАКТАЛЬНЫХ ХАРАКТЕРИСТИК ГИДРОДИНАМИЧЕСКИХ ПОТОКОВ

Аннотация. *На основании фрактальных методов обработки изображений проанализированы ламинарные и турбулентные гидродинамические потоки. Вычислены фрактальные размерности изображений гидродинамических потоков методами классического и модифицированного Box Counting, проведен сравнительный анализ результатов. Построены эмпирические распределения локальных фрактальных размерностей и фрактальные кепстры.*

Ключевые слова: *гидродинамический поток, фрактальная размерность, самоподобная структура, фрактальный кепстр (сигнатура), эмпирическое распределение локальных фрактальных размерностей*

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АНАЛІЗ ФРАКТАЛЬНИХ ХАРАКТЕРИСТИК ГІДРОДИНАМІЧНИХ ПОТОКІВ

Анотація. *На підставі фрактальних методів обробки зображень проаналізовані ламінарні і турбулентні гідродинамічні потоки. Обчислені фрактальні розмірності зображень гідродинамічних потоків методами класичного і модифікованого методів Box Counting, проведений порівняльний аналіз результатів. Побудовані емпіричні розподіли локальних фрактальних розмірностей і фрактальні кепстри.*

Ключові слова: *гідродинамічний потік, фрактальна розмірність, самоподібна структура, фрактальний кепстр (сигнатура), емпіричний розподіл локальних фрактальних розмірностей*

Introduction. One of the main problems is designing of elements transportation systems (ETS) of liquids or gases is the lack of universal methods for calculating coefficients of local hydraulic resistance in the ETS complex shape such as collectors, turns, tees, sudden expansion or contraction and etc. The contribution of these elements in the general hydraulic resistance of transportation system with short pipelines according to some estimates can exceed 40 % [1]. Herewith research of Ukrainian and foreign scientists, which work in the areas of mechanics liquid and gases, hydraulic and aerodynamic cars and information Technology show that most important theoretical and practical problem is considered to identify and research of influence structure of hydrodynamic flows at local resistance in ETS complex shape [2 – 4].

For its decision is necessary modern means of technical diagnostics, allowing to eliminate incompleteness and uncertainty of information hydrodynamic flows in ETS complex shape. Suggested system of designing ETS, which considers in them structure of hydrodynamic flows contains three main blocks: receiving of visual data about the structure of hydrodynamic flows, their intellectual analysis and making project decision about the construction ETS with considering of new significant information about the structure of hydrodynamic flows. The visual data about the state of hydrodynamic flows are images of artificial surfaces of distribution intensity (color), which definitely characterize field of gradients velocity (pressure) hydrodynamic flows in physical prototype of ETS. The dynamical artificial surface of distribution gradients of (pressures) hydrodynamic flows obtained by conducting of physical modeling with using of method visualization of discrete structures flow [5 – 6].

This method refers to the class of polarization - optical methods of visualizing transparent working bodies with the help of optically active liquids. To automate the design decision about construction ETS suggested conducting comprehensive analytical and visual processing of semi-structured data of physical modeling, the purpose of which is to obtain images of hydrodynamic flows with intellectual data. These data reflect the relevant information about the structure (distribution of parameters) hydrodynamic flows in ETS, and their visualization, for example with the help of pseudo coloring of individual pixels or images areas allow to reduce the dimension of the analyzed surfaces [7 – 11].

On the other hand, hydrodynamic flows represent a complex natural process that has a fractal nature. That's why is actual research of their images with the help of fractal methods.

Getting of fractal characteristics of hydrodynamic flows. On Fig. 1, c and d represented with using of method visualization discrete flow, images of laminar hydrodynamic flows, under which liquid moves layers without stirring and pulsations (i.e. without promiscuity fast changes of velocity and pressure). On Fig. 1, a and b represented turbulent hydrodynamic flows, arising from the increase speed of flow liquid and forming as the numerous non-linear fractal waves.

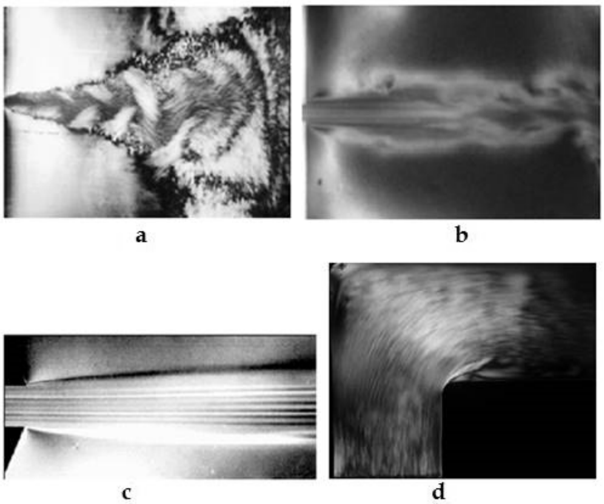

Fig. 1. Hydrodynamic flows:
a and b – turbulent; c and d – laminar

In the course of these studies such fractal characteristics determined as the fractal dimension, the distribution of the local fractal dimensions and a fractal signature. The fractal dimension of images hydro streams was determined by two methods: classical and modified methods BOX COUNTING, which can be applied to the images of the various structure and allow us to determine the fractal dimension is not strictly self-similar objects. To estimate the fractal dimension of a classical algorithm BOX COUNTING is the Euclidean space, which contains an image of the object is divided with a grid cell size and counted non-empty, occupied by the object under study squares. Further, the size is reduced and again counts the number of non-empty fields. The slope of the graph in the logarithmic scale corresponds to the value of the dimension [13].

In evaluating the fractal dimension of the modified algorithm BOX COUNTING, in the classical algorithm introduced a number of changes. Euclidean space, which contains an image of the object, is divided grid with a cell size and counted non-empty, occupied by the object under study squares. In this non-empty squares are only those that contain the border. Further actions are coincide with the classical algorithm: the size is reduced and then count the number of non-empty fields. The slope of the graph in logarithmic scale corresponds to the value of the dimension. The complexity of implementing of this algorithm is that the image comprises full colored squares that should be considered only if they are boundary. Fully colored square is considered the boundary if at least one of the adjacent squares are not painted. The difference of meanings obtained for the two algorithms is that depending on the configuration of the boundary may be lost squares, which were recorded in the classical algorithm [14].

Classic algorithm allowed to estimate the fractal dimension of the entire structure of the flow and the modified is estimates only border flows [12]. Wherein analysis carried out taking into account the environment and without taking into account the environment (on the fragment contains directly stream). In the Tabl. 1 and Tabl. 2 were showed the results of calculations of the fractal dimensions of hydro streams.

1. Meanings of the fractal dimension of the hydrodynamic flows (classical algorithm)

Images in Fig. 1	Meanings of fractal dimension, which is calculated with the help of classical Box Counting	
	Image entirely (with record of environment)	Fragment of image (without of record environment)
a	1,8906	1,9663
b	1,9076	1,9779
c	1,9457	1,9671
d	1,9528	1,9733

In calculating of the fractal dimension of the images of the hydrodynamic flows with the record of the environment, classic Box Counting showed that the dimension of the turbulence was 1,90 and for laminar was 1,95. When rendering fragments covering exclusively flows, the classic method gave the result 1,97 for laminar and turbulent for hydro- flows not allowed to classify the type of the flow. In this modified Box Counting allowed to distinguish the type of flows on the fragments (for laminar were received meanings in the range 1,22 – 1,32, for turbulent is 0,81 – 0,94) but not showed no sensitivity for images streams environment.

To construct the fractal distributions sliding window method is used. This method consists of determining the fractal dimension within the window, the size of which can be set arbitrarily. The window is moved pixel by pixel over the image. At each step the computations of the fractal dimension. The size δ of the window depends on the scale and is calculated from the relation $2\delta+1$ [14]. On the basis of classical and modified algorithms were built fractal distributions.

2. Meanings of fractal dimension of hydrodynamic flows (modified algorithm)

Images in Figure 1	Meanings of fractal dimension, which is calculated by modified Box Counting	
	Image entirely (with record of environment)	Image entirely (with record of environment)
a	1,3044	1,3044
b	0,9915	0,9915
c	1,3053	1,3053
d	1,1812	1,1812

Fig. 2 shows the empirical distribution of the local fractal dimensions in the scale $\delta = 7$ (sliding window size of 15x15 pixels) [13], which correspond to the hydrodynamic flow, shown in Fig. 1, excluding the environment (for the fragments of the image). Fractal distributions on the fragments gave a more multimodal character that suggests about closer look structure itself flow. Every mode of such distribution correspondent to cluster of image has close meanings of the local dimensions.

The most homogeneous character fractal distribution has hydro-dynamical flow shown in Fig. 1d, as indicated in Fig. 2, d. Most non-homogeneous fractal distribution, which consists of 4 events, has a laminar hydrodynamic flow shown in Fig. 1, c. To be able to distinguish fractals having elements of different sizes, it is necessary to analyze at several scales simultaneously. In this case, the dependence of the measures on the scale $S = f(\delta)$ in the logarithmic scale is fractal signature fractal cestrum), which determines out of relation:

$$S = N\delta, \quad (1)$$

where N is the number of elements required to cover the object; δ is a square of element bins.

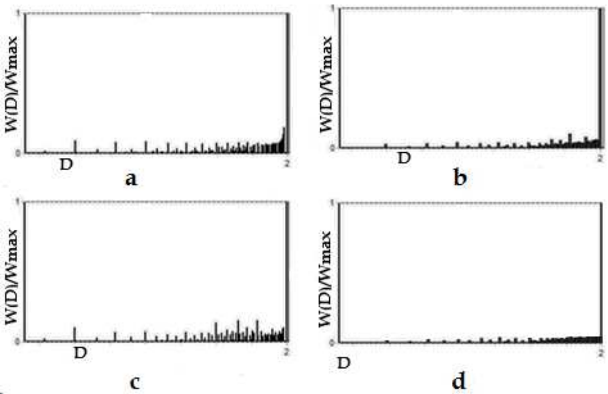

Fig. 2. Empirical distribution of local fractal dimensions correspondent of hydro-dynamic flows submitted on Fig.1 without record of environment

Fig. 3 shows the fractal signature and derivatives of hydrodynamic flows shown in Fig. 1. fractal signature is dependent on the scale of assessments of the type of monitoring. The greatest differences in the signatures and their derivatives allow determining the average size of the structure elements of the study [14].

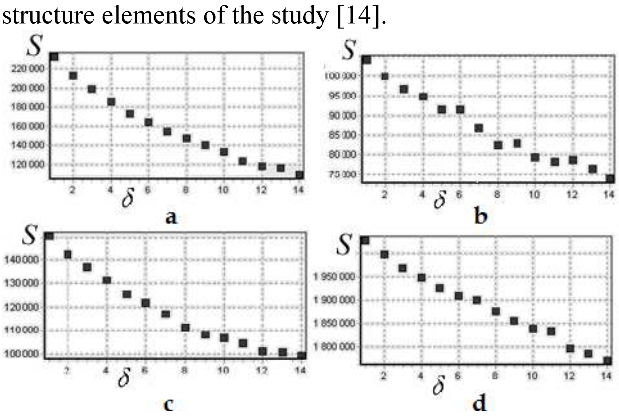

Fig. 3. Fractal signatures of hydro-dynamic flows, submitted on Fig. 1

Built a fractal signature can distinguish self-similar objects and to determine the size of some of their elements. If the image is composed of several self-similar structures, the differences signatures will manifest in several ranges of the scales.

Conclusions. Based on fractal methods of images processing techniques are analyzed laminar and turbulent hydrodynamic flows. Calculated fractal dimensions of images of hydrodynamic flows techniques of classic and modified Box Counting, a comparative analysis of the results. Empirical distributions were built of local fractal dimensions and fractal cestrum. A software product was developed that allows evaluating the fractal dimension of the distribution of local and building of local fractal dimensions. It was found that the classical fractal dimension of the images of hydrodynamic flows, taking into account of the environment to turbulent flows fractal dimension was 1,90, and for laminar it was 1,95. When rendering fragments spanning exclusively flows, the classical method gave the results 1,97 for laminar and turbulent for hydro-flows not allowed to classify the type of flow. Wherein modified Box Counting make it possible to distinguish the type of streams on the fragments (for laminar got meanings in the range of 1,22 – 1,32, for turbulent is 0,81 – 0,94) but does not show a sensitivity for images flows with the environment.

Images which composed a lot of fragments of different nature after calculating the dimensions of local give multimodal distributions, indicating that the different clusters sizes containing in the structure. Fractal distributions of the hydrodynamic flows on the fragments gave a multi-modal character, which indicates of a more detailed examination of the structure of the flow.

It should be noted that the modified algorithm BOX COUNTING should be used for determining of fractal dimension of tracking changes boundaries of objects, but the construction of fractal distributions based on it does not make sense.

Further studies show that receiving of significant information about structure (distribution of parameters) hydrodynamic flows allow to automate process of designing ETS complex shape such as collectors, turns, tees, sudden expansions or contractions and so on and reduce their hydraulic resistances from 10 to 40 % and thus reduce the energy consumptions during operation of transporting liquids or gases.

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