

On the Issue of Visualization of the Almost Periodic Structure of a Snow Avalanche

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Abstract

The article considers the specifics of interpreting the results of almost periodic analysis in the problem of structural segmentation of a snow avalanche, applicable to increasing the efficiency of forecast models and improving avalanche control measures. The preliminary stage of linearization of the avalanche structure is based on the polygonal approximation of the body area of the phenomenon, presenting the data in a rectangular format. The study of straightened data allows us to form a network of uniform rectangular areas of uniform data, for which the problem of displaying the markup on the original data arises. Such markup allows us to clearly separate the areas of laminar and turbulent avalanche descent, as well as to highlight the significant boundaries of the areas of onset, development and braking of the snow mass. The article provides mathematical and algorithmic support necessary for reproducing longitudinal and transverse boundaries on the original data for sequences of polygons of arbitrary duration. The results can be applied in the development of visualization systems, warning and prevention of avalanche activity, thereby stimulating the strengthening of the effectiveness of measures to prevent damage from hazardous natural phenomena.

Keywords: almost periodic analysis, data analysis, image processing, avalanches, natural hazards, visualization, polygonal transformation.

1. Introduction

Modern climate trends are accompanied by an increase in emergency situations associated with dangerous natural phenomena, among which avalanches stand out. Avalanches are common in many countries - in Russia, Kazakhstan, Tajikistan and others. Their activity is destructive in nature, and therefore arouses significant interest in forecasting [1-3].

Within the framework of avalanche analysis, both the mechanisms of avalanche occurrence and the mechanisms of interaction of the snow mass with infrastructure are studied [4, 5].

An important stage of the study is the visualization of the model - for this, specialized programs and analytical complexes are used [6].

Visualization of the phenomenon model allows you to effectively solve the problems of phenomenon segmentation, which can improve the results of analytical models - for example, the RAMMS model demonstrates satisfactory results even in conditions of insufficient data [7, 8].

In this case, zoning by hazard degrees played a significant role in the analysis. Thus, the issue of structural segmentation of an avalanche shows its relevance in order to improve the quality of forecast models.

Among other models of analysis for the qualitative study of data with an ordered argument, one can single out the model of almost periodic analysis based on a generalized shear

function. Its application in the problem of segmentation of a dangerous natural phenomenon using tropical cyclones as an example has shown high efficiency [9].

Almost-periodic analysis is a mathematical tool for studying empirical data represented by records of the function $y(t)$ ordered by a uniform argument. To identify the values of characteristic intervals of uniform data behavior, called almost-periods, the values of the generalized shift function (1) are calculated for a set of values of the function $y(t)$:

$$a(\tau, \Delta t) = \frac{1}{n - \tau - 2\Delta t} \cdot \sum_{t=1}^{n-\tau-2\Delta t} \left| \ln \left(\frac{y_{t-\Delta t+\tau} \cdot y_{t+\Delta t+\tau}}{y_{t+\tau}^2} \right) - \ln \left(\frac{y_{t-\Delta t} \cdot y_{t+\Delta t}}{y_t^2} \right) \right|, \quad (1)$$

where n is the total number of samples of the function $y(t)$; t are integers representing the argument values of the function $y(t)$; Δt is a positive integer representing the shift in the argument; τ is a positive integer representing the near-period values.

Local minima of the resulting function are analyzed for various values of the Δt argument, and the most significant and consistent values are identified, representing near-periods for the set of values under study. The results of processing the generalized shift functions for all rows and columns of the image are summarized, and the most common near-period values are identified, characterizing the avalanche structure under study in the image.

An approach to visualizing the results of almost periodic analysis applied to graphical data on a snow avalanche is proposed.

2. Almost periodic analysis in the problem of structural segmentation of an avalanche

In the course of processing images of dangerous natural phenomena such as avalanches, various methods of analysis can be used, pursuing their own goals. One of the problems solved in this area is the structural segmentation of an avalanche, which involves identifying characteristic parts, points, lines and boundaries of stable behavior areas. To solve such a problem, one can use quasi-periodic analysis based on the selection of rhythmic characteristics describing intervals of uniform data behavior.

Almost periodic analysis can be carried out both in relation to the data of the original image and in the processed area. Thus, a rational solution seems to be localization of the area of the phenomenon body on the entire image, and reduction of the data to a straightened form. For this purpose, the polygonal linearization algorithm can be used, reducing avalanche structures of arbitrary shape to a rectangular form, in which it becomes possible to carry out quasi-periodic analysis in relation to horizontal and vertical sections. The results of the almost periodic analysis were presented in the form of rhythmic beats defining intervals of uniform behavior of a function with an ordered argument.

As part of the study of linearized data, the almost periods defined the structural marking of the system into rectangular sectors.

For the practical implementation of the results, a description of the algorithm was carried out that forms the reproduction of the structural marking of the identified boundaries on the studied data.

3. Mathematical support of the algorithm

During the almost periodic analysis of the avalanche structure in linearized coordinates, the polygons form an approximating network that describes the geometric specifics of the phenomenon.

Let us consider the main approach used to reproduce the boundaries, which are segments connecting the opposite sides of the polygon quadrangles, on the space of the original image based on the coordinates of the polygon vertices.

For a polygon with vertex coordinates (x_1, y_1) , (x_2, y_2) , (x_3, y_3) and (x_4, y_4) with a given transverse sampling frequency N , the boundary along the i -th cut passes along the segment connecting the points $\left(x_1 + i \cdot \frac{x_2 - x_1}{N}, y_1 + i \cdot \frac{y_2 - y_1}{N}\right)$ and $\left(x_3 + i \cdot \frac{x_4 - x_3}{N}, y_3 + i \cdot \frac{y_4 - y_3}{N}\right)$.

Thus, for a polygon with the number of transverse divisions 7, the boundary number 4 is shown by a dotted line in Fig. 1.

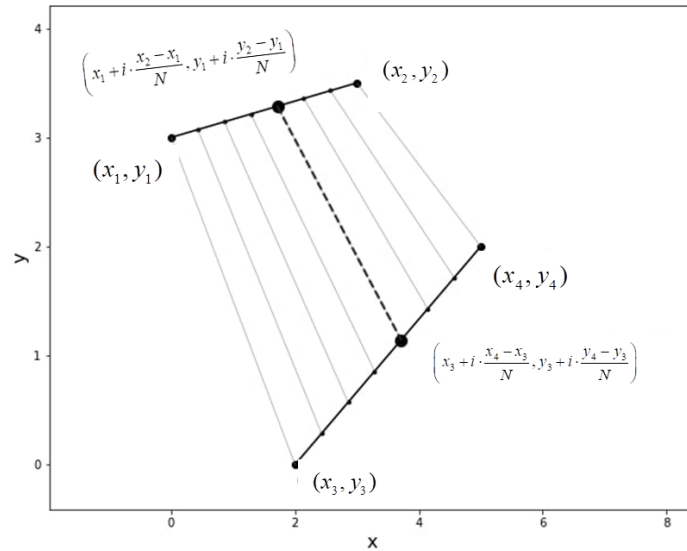


Fig.1. Reproduction of a longitudinal boundary in a polygon

Thus, to draw longitudinal boundaries of structural segmentation in each polygon, i -th segments are drawn sequentially. Thus, an example of the 8th longitudinal boundary for dividing the image into 10 strips is shown in Fig. 2.

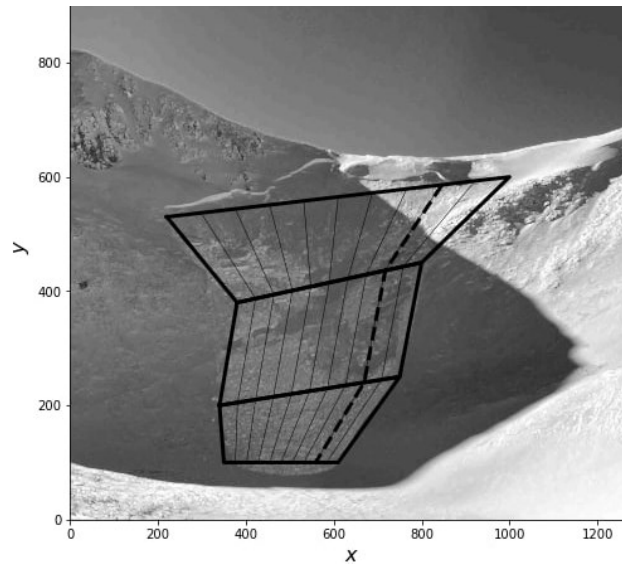


Fig.2. Reproduction of a longitudinal boundary in a system of polygons in the space of the image under study

In the case of constructing transverse boundaries, the segment is constructed in a polygon with a longitudinal sampling frequency M along the j -th section between points with coor-

dinates $\left(x_1 + j \cdot \frac{x_3 - x_1}{M}, y_1 + j \cdot \frac{y_3 - y_1}{M}\right)$ and $\left(x_2 + j \cdot \frac{x_4 - x_2}{M}, y_2 + j \cdot \frac{y_4 - y_2}{M}\right)$. Thus, the 2nd boundary for 7 longitudinal sectors inside the polygon is shown by a dotted line in Fig. 3.

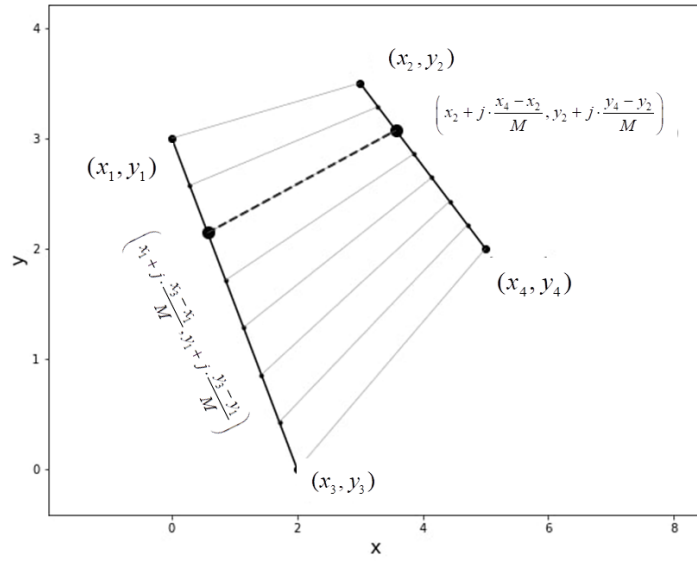


Fig.3. Reproduction of the transverse boundary in the polygon

To reproduce the j -th transverse boundary in the structure of a sequence of polygons with longitudinal sampling frequencies K_i , it is necessary to determine the polygon number based on the inequality $\sum_{i=0}^{p-1} K_i < j \leq \sum_{i=0}^p K_i$.

Then the $\left(j - \sum_{i=0}^{p-1} K_i\right)$ -th slice is carried out in the p -th polygon with the sampling frequency K_p .

Thus, as an example, the appearance of the 8th transverse boundary is shown by the dotted line in Fig. 4.

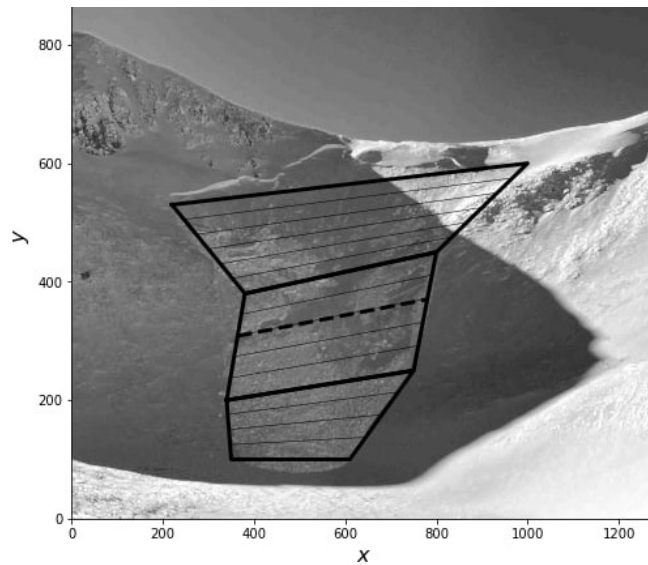


Fig. 4. Reproduction of a longitudinal boundary in a system of polygons in the space of the image under study

Thus, the principles of constructing longitudinal and transverse boundaries within polygon systems are described.

Let us consider the features of the algorithm that reproduces boundaries in a uniform tact mode within the framework of constructing a system of rhythmic structuring of the studied snow avalanche.

4. Algorithm for reproducing structural segmentation of an avalanche on the original data

To mark a regular system of longitudinal almost periods of size Tl and transverse almost periods Tt in a structure of P linearizing polygons with given transverse sampling frequencies Nl and a system of longitudinal samplings Nt_i , an algorithm is proposed, the diagram of which is shown in Fig. 5.

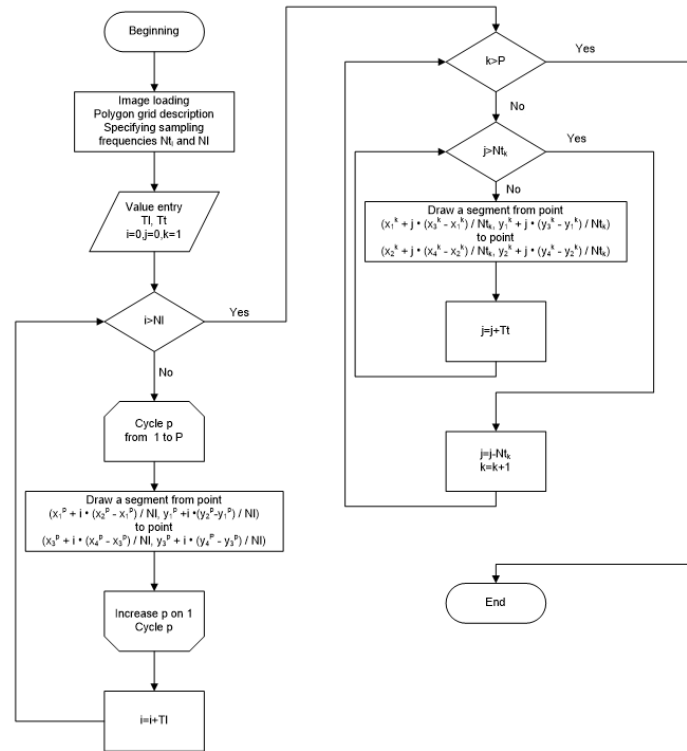


Fig. 5. Graphic description of the algorithm for reproducing the structural segmentation of the object under study using the initial data: Nt_i is the longitudinal sampling frequency of the i -th polygon; Nl is the transverse sampling frequency of the polygon system; Tl is the value of the transverse almost period; Tt is the value of the longitudinal almost period; i, j, k are auxiliary iterator variables; p is the polygon number variable; P is the number of polygons; x_i^j, y_i^j are the i -th ($i = 1, 2, 3, 4$) coordinates of the j -th polygon, the relative position of which is determined according to Fig. 1 and Fig. 3.

To implement the algorithm for this study, a program was developed in the Jupiter Notebook development environment using Python 3.7. The plot module of the matplotlib library was used for graphics processing. The black-and-white image data was represented as a matrix of pixels with values ranging from 0 to 255, allowing it to be displayed using the contourf module, which is designed for displaying contour representations of data.

For efficient processing of datasets represented as vectors and matrices, the NumPy library was used.

The program's implementation in Python ensures cross-platform compatibility, allowing deployment and use on major public operating systems (Windows, Linux, macOS).

Within the framework of the developed program, the user is able to form approximating polygonal representations of the processed image area, set the frequencies of longitudinal and transverse sampling, and also select the near periods displayed in the polygon system based on the algorithm presented in the work.

An example of the algorithm implementation on an avalanche image for a grid of 3 polygons with a transverse sampling frequency of 300 nodes, and a longitudinal sampling of 600 nodes in total with a distribution of 200, 250, and 150 nodes, respectively. The reproduction of a transverse almost period of 87 sampling nodes and a longitudinal almost period of 155 sampling nodes is shown by dotted lines in Fig. 6.

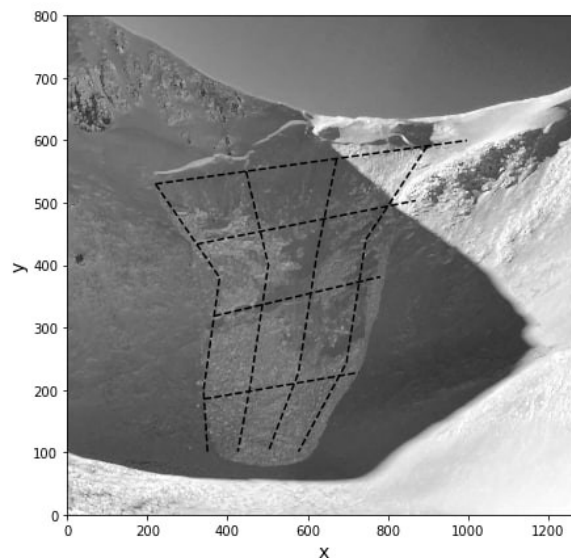


Fig. 1. Structural segmentation of the studied snow avalanche

It should be noted that Fig. 6 clearly shows how the developed structural segmentation algorithm separates the boundaries of the laminar and turbulent snow avalanche regions. The division by longitudinal boundaries into three segments reproducing avalanche descents from two ridges and the merging of these flows in the middle was explicitly recorded. Transverse boundaries cut off the descent start cycle, the interval of the movement bend, and the final period of avalanche braking.

The obtained results allow us to predict avalanche activity to ensure sustainable and high-quality development of regional infrastructure and support decision-making in the design of avalanche protection structures.

5. Conclusion

An algorithm for reproducing rhythmic structural segmentation of the boundaries of laminar and turbulent areas of a snow avalanche has been developed. A mathematical basis for visualizing boundaries in single polygons is provided, as well as an algorithm that implements a systematic approach to constructing longitudinal and transverse boundaries in systems of linearizing polygons.

Graphic examples demonstrate the possibilities of constructing single longitudinal and transverse boundaries on the initial data, as well as their almost periodic system of spatial structuring.

The results obtained can be useful in increasing the accuracy of avalanche activity forecasting models, as well as in designing avalanche protection structures to minimize damage to the population and infrastructure.

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