The use of neural network technologies to optimize the shape of an object during mass transfer of air

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Abstract. In this article, the authors propose using a neural network to optimize the aerodynamic drag of a body in a gas flow. The use of such optimization methods using evolutionary algorithms makes it possible to obtain a mathematical model that describes the shape of the aerodynamic profile, which allows the operator to easily change parameters. It is shown that the value of the drag force for a body of optimized shape is lower than the values for bodies of rotation and known profiles taken for comparison. As bodies, we can consider parts of engineering structures in the air flow, parts of vehicles, and bodies located in the air flow in the duct, in particular in the duct of the photo separator. The latter is important from the point of view of neural network photo separation of seeds and grain.

1. Introduction
Obtaining optimal aerodynamic characteristics is of particular great interest, especially taking into account the need to obtain the exact solution of equations, which in itself is a rather difficult task. At the moment, there are a number of developed methods that can predict and show the forces acting on the object of study in the flow and give an idea of what resistance forces act on a body of a given shape. Analytical methods [1-3], CFD analysis methods [4] can be applied, but all of them are time-consuming and not accurate enough, or require large production capacities.

When using traditional approaches for approximation, as a rule, it is required that the experimental characteristics of the object under study be obtained on a regular grid of parameters, but this is not possible for all types of experiments. Artificial neural networks are a promising mathematical apparatus for processing and approximating data from a full-scale experiment. By their mathematical nature, these networks are universal approximators of functions of a set of variables, which makes it possible to effectively use them to determine the aerodynamic characteristics of an object after tuning on the available experimental data obtained, including on irregular grids of parameters. In general, the use of artificial neural networks makes it possible to create a fairly simple process for processing the primary experimental data in the form of a digital code, convenient for further use in existing calculation systems.

Moreover, even with arrays of experimental data obtained in the study of object models, it is necessary to carry out approximation in a multidimensional space of variables.

In this work, the authors carried out the development of a system that implements the geometry of the object of study, taking into account the imposed restrictions and pre-defined boundary conditions. A method is presented that includes the use of neural network algorithms that, based on evolutionary methods, using as input data the study area of a given body shape and flow velocity, would obtain an
optimal geometric structure based on data on the initial velocity and the initial shape the object of study. The main evaluation criterion is an indicator of the aerodynamic quality of the object [5-8].

Despite the huge selection of objects, in this work, we will be primarily interested in the object of study - grain in the duct of the photo separator [9, 10].

Small impurities, as a rule, are wetter than the main grain, do not stand out and, together with the grain, go either to temporary storage or to the dryer. They fill in the intergranular spaces of the embankments and reduce the duty cycle, which significantly increases the resistance to air passage, and, in turn, leads to caking of the grain material. Drying and cleaning of such grain becomes inefficient and economically costly.

Dusty air from the aspiration channels of grain cleaning machines through the air ducts of the aspiration system enters the cyclones, is cleaned of dust and discharged into the environment.

For high-quality final cleaning, first of all, the use of modern automation tools is necessary. The correct organization of this process allows you to remove all substandard obtained as a result of previous operations, to obtain a homogeneous product, to exclude extraneous inclusions and to conduct a visual inspection of the product before storage or packaging. The last stage of processing can be automated by photo separators - machines for separating the product by color parameters.

The photo separator is designed to sort any loose products (cereals, legumes, industrial and oilseeds, grass seeds) by physical and optical properties - by color, color shades, shape, size and structure.

The photo separator allows, having one technological unit, to process several products (varieties) according to different parameters. This means reducing costs for production facilities, equipment, and personnel. The quality of products after processing with a photo separator allows you to increase the percentage of output of the highest grade due to lower grades. This, in turn, will also increase the financial return of the agricultural enterprise and the overall level of agricultural production.

2. Development of a numerical model

Today, an important characteristic of the development of aerodynamics, as a science, is a steady increase in the requirements for technical characteristics, functional capabilities of various devices and machines for various purposes. However, the desire to increase the capabilities of technology, expressed in the expansion of functionality, application areas and other factors, leads to the need for significant complication of both the equipment design and devices in general, and their individual parts and assemblies.

Thus, to achieve such functionality and ensure their further expansion, a significant complication of the design of such systems is necessary. This leads to the emergence a large class of tasks related to the transfer, processing and storing large amounts of information.

In this regard, the problem of increasing the reliability and safety of such systems becomes an increasingly urgent problem. The creation and development of complex engineering systems of a modern level, currently requires an approach based on new methods of calculation, modeling and design. To solve the described problems, today more and more new methods find application, based on the use of systems with artificial neural networks. An artificial neural network is a mathematical method of simulating processes and phenomena, based on modeling the operation of the studied object and allowing reproducing the dependencies of its parameters and characteristics. Modern neural networks already make it possible to solve unsuccessfully problems with a large number of variables, without requiring a large amount of computing resources (compared to standard computing methods).

In the software package developed by the authors of [4], we set up the curve of the object of study by a set of points (table 1), in accordance with the previously created sample.

Let us perform the import and get the result shown in Figure 1.

Performance optimization is carried out in several stages. As a template, one of the predefined objects is selected. First, the shape parameters are adjusted in accordance with the selected body shape. Due to the limited accuracy of the curve fitting and the limitations resulting from the relatively small number of free parameters of the equation, there may be some difference compared to the sample.

In the developed package, the object of study is described by the following equation:
\[
X(\theta) = 0.5 + 0.5 \frac{|\cos\theta|^B}{\cos \theta}, \\
Y(\theta) = \frac{T}{2} \frac{|\sin\theta|^B}{\sin \theta} (1 - X^P) + C \cdot \sin(X^E \pi) + R \cdot \sin(X^2 \pi),
\]

(1)

where B is the coefficient of the basic shape of the object front part, T is the thickness of the object chord, P is the taper indicator (at P = 1 when shifted to the back edge, the thickness approaches 0 in a linear way), C is the camber, as a fraction of the chord, E is the camber index, which determines the location of the maximum camber point (E = 1 describes a 50% camber point, and a lower value shifts it in the direction of the front edge), R is the reflex index. A positive value generates a reflex back edge, and a negative value emulates flaps.

Table 1. A set of study object points for further import into the modelling environment.

| X      | Y      | X      | Y      |
|--------|--------|--------|--------|
| 0.00000000 | 0.00000000 | 0.93138945 | -0.01366696 |
| 0.99618780 | -0.00075923 | 0.92756825 | -0.01442528 |
| 0.99237561 | -0.00151845 | 0.92374762 | -0.01513450 |
| 0.98856341 | -0.00227768 | 0.91989727 | -0.01566748 |
| 0.98475121 | -0.00393699 | 0.91694692 | -0.01629945 |
| 0.98993991 | -0.00379613 | 0.91219657 | -0.01673342 |
| 0.97712682 | -0.00455535 | 0.90834621 | -0.01726649 |
| 0.97331462 | -0.00531458 | 0.90449586 | -0.01779937 |
| 0.96959242 | -0.00697389 | 0.90064551 | -0.01833235 |
| 0.96569922 | -0.00683393 | 0.89679516 | -0.01885352 |
| 0.96187893 | -0.00759225 | 0.89294481 | -0.01939839 |
| 0.95896583 | -0.00835148 | 0.88999446 | -0.01993127 |
| 0.95425363 | -0.00911979 | 0.88524419 | -0.02046425 |
| 0.95944144 | -0.00986993 | 0.88139375 | -0.02099722 |
| 0.94662924 | -0.01062916 | 0.87754349 | -0.02153919 |
| 0.94281794 | -0.01138338 | 0.87369395 | -0.02296317 |
| 0.93999484 | -0.01214761 | 0.86984279 | -0.0239614 |
| 0.93519265 | -0.01299683 | - | - |

Figure 1. Model of the study object.
Performance optimization performed in several stages. As a standard, one of the existing objects is selected [2]. First, the form parameters are configured in accordance with the selected object profile. Due to the limited accuracy of the curve fitting and the limitations resulting from the relatively small number of free parameters of the equation, there may be some difference compared to the original object.

The study was carried out on the basis of an axisymmetric object [4] with different parameters B, T, P. The value of the gas flow rate was chosen as a variable for simulation.

The main parameters of the profile B, T, P are selected as optimization.

The parameter for changing the geometry of the object’s shape is chosen equal to 0.2 (20% of the initial shape).

3. Results

The obtained results show a significant increase in aerodynamic quality index. The graphs show that the simulation by 20 percent or more increases the maximum parameter of aerodynamic quality. Thus obtained geometry is somewhat modified from the original one. Characteristic is rounding of the front part of the upper and lower chords of the object, an increase in the curvature radius of the nose of the object, and a change in the rear part, expressed by narrowing the back edge. This is justified by the fact that a necessary component of reducing the drag coefficient is such a body shape that could ensure that at a given speed, the flow is kept smoothly off the chord, and not its disruption. As analysis shows, a method based on neural networks with evolutionary genetic algorithms allows optimization of the shape of an object according to specified initial characteristics.

As a result of the conducted research, the prospects of using artificial neural networks in various fields of science and technology were shown. The use of neural networks at the design stage of equipment and its parts can significantly improve the reliability and performance characteristics, which makes it possible to reduce the cost of creating systems by reducing the costs of field tests and laborious calculations.

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