Evolutionary method for automated design of models of vortex flowmeters transformation function

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Abstract. The approach to improving the accuracy of flow measurement using vortex flowmeters is discussed. One of the ways of flow measurement accuracy improvement is finding the suitable flowmeter transformation function. Such task is difficult to formalize and is usually solved by expert means. The approach for automatic selection of the vortex flowmeters transformation function form is described. The method is based on the evolutionary method for solving the symbolic regression problems. This is a genetic programming method. A description of the approach is given. The numerical study conditions of the proposed approach reliability are presented concerning the problems of determining the vortex flowmeters transformation function formula. The analysis of the obtained results makes it possible to state that the proposed approach allows solving the problem efficiently. The prospective direction of designing an adaptive transformation function is stated on the basis of modifications of the genetic programming method.

1. Introduction

In modern production the control of the flow of liquid or gas is an integral part of many technologies and production processes. Flowmeters are intended to be used as means of commercial accounting and technical control in various technological processes at enterprises of all kinds, for example, the enterprises of heat, power, chemical, food and other industries. The oil and gas industry is one of the leading industries for which the use of flowmeters is a most important metrological task. Vortex flowmeters are widely used in the oil and gas industry [1].

The vortex method of flow measurement is based on Van Karman phenomenon. A vortex path is formed behind a body when a fluid flows past the body. Bluff bodies are used as flow bodies, and the detection of vortices is performed using an ultrasonic beam. In this case the frequency of the vortices formation is directly proportional to the flow velocity. It is shown that flow volume can be represented as a single-factor transformation function depending on the frequency of the vortex formation [2].

The problem of improving the accuracy of flow measurement with the help of vortex flowmeters remains topical. The solution of the problem will allow reducing production and economic losses for technological processes, the measurement of costs which are crucial for balancing and economic calculations.
2. Improvement of vortex flowmeters accuracy

2.1. Methods for vortex flowmeters accuracy improvement
The methods for vortex flowmeters accuracy improvement are divided into three main groups [3, 4]. The first group includes approaches to optimization of the shape and geometric parameters of the flow body and the flow part of the flowmeter. Producers of vortex flowmeters prefer to use flow bodies of forms that are easy to manufacture, such as a trapezoidal prism. In the process of designing the choice of specific geometric parameters is based on the operating characteristics of the particular brand of the flowmeter.

The second group includes research methods connected with the sensor and the device for processing the signals of the measuring information from vortex flowmeters. The aim of these methods is to increase the accuracy of finding the frequency of the vortex formation behind the flow body. The methods are promising; however, they require rather powerful computing facilities or complexity of construction, which is economically justified only in high-precision and expensive flowmeters.

The given paper focuses on the third group of methods for improving the accuracy of vortex flowmeters. The aim of these methods is to improve the accuracy of flow measurement by finding a suitable flowmeters transformation function. Reducing the measurement error of small fluid flow by selecting and justifying the transformation function is a promising method, since it gives an increase in the measurement accuracy without changing the design of the flowmeter.

The problem of finding a suitable model of the transformation function is an unformalized procedure. The choice of the model type of the transformation function is made on the basis of a priori information about the means of measurement and the experience of the researcher. To find a common model of the conversion function for the brand of flowmeters suitable for a range of sizes (diameters) is an important problem. Obviously, automation of the choice of the form of the transformation function will allow making such a choice quickly enough and carrying it out for different models and sizes of flowmeters.

The paper proposes an approach to automation of the vortex flowmeter transformation function based on the automatic regression models recovery method in the form of functions. This method involves the use of the method of solving the problem of symbolic regression - the method of genetic programming [5, 6]. Further on, the paper describes the method of genetic programming briefly and presents the results of the study of the approach application for various initial data.

2.2. Genetic programming approach
The task of symbolic regression is to find a symbolic mathematical expression that approximates the relationship between the input variables and their corresponding output variables. The solution of the problem of symbolic regression is either an actual computational procedure or a symbolic mathematical expression. At the present stage the methods for solving the problem of symbolic regression have not been developed quite well. Genetic programming is one of the most promising approaches in this direction. Symbolic regression allows us to obtain not only a computational procedure but also a formula (a symbolic mathematical expression) that can be subjected to meaningful analysis and simplified.

The main idea of the genetic programming method is to obtain a dependency describing the data presented in the original samples. It uses the software implementation of procedures simulating evolutionary processes from a randomly generated set of functionals [7]. Decisions in genetic programming can have various forms and different sizes. The most commonly used representation of decisions is the form of trees [8].

A tree is a directed graph in which each successive vertex is associated with one and only one previous vertex. The set of all possible internal vertices of a tree is called a functional set. The set of all possible external vertices of a tree is called a terminal set. Elements of a functional set usually are operations and functions. Variables and constants are usually chosen as the elements of the terminal set. Figure 1 shows the block diagram of the genetic programming approach.
The following describes the conditions and the results of an experimental study of the efficiency of the proposed approach for designing a model of the flowmeter transformation function.

3. Experimental study

3.1. Test problems

Each test problem includes a possible flowmeter transformation function. These test functions are considered in a number of studies devoted to the selection of the transformation functions of vortex flowmeters [9, 10]. The type of the studied transformation functions is given in Table 1.

3.2. Modeling criterion

Relative mean error (1) was used as a criterion of modeling accuracy during numerical investigation.

\[
W = \frac{1}{n\left(y_{\text{max}} - y_{\text{min}}\right)} \sum_{i=1}^{n} \left| \hat{y}(x_i) - y_i \right|.
\]  

Here \(i\) is the observation number in the approximated sample, \(i = 1,n\), \(n\) is the number of sample points, \(y_{\text{max}}\) and \(y_{\text{min}}\) are the maximum and minimum values of the output parameter respectively.

The condition of achieving the level of relative modeling error and the fulfillment of a given number of calculations of the function were used as criteria to stop calculations. The effectiveness of the method was evaluated by reliability criteria. Statistical data for obtaining reliability estimates was collected during 50 runs of the algorithm. The results are presented in Table 1.
Table 1. Results of numerical experiment for different test problems.

| Test problem | Flowmeter Transformation Function | Reliability of the Approach |
|--------------|----------------------------------|-----------------------------|
| 1            | $y = b_0 + b_1/x$                | 0.990                       |
| 2            | $y = 1/(b_0 + b_1 x)$            | 0.995                       |
| 3            | $y = x/(b_0 + b_1)$              | 0.985                       |
| 4            | $y = b_0 \cdot b_1^x$           | 0.990                       |
| 5            | $y = b_0 \cdot e^{b_1 x}$        | 0.995                       |
| 6            | $y = 1/(b_0 + b_1 e^{-x})$      | 0.965                       |
| 7            | $y = b_0 \cdot x^4$              | 0.990                       |
| 8            | $y = b_0 + b_1 \log x$           | 0.980                       |
| 9            | $y = b_0/(b_1 + x)$              | 0.985                       |
| 10           | $y = b_0 \cdot x/(b_1 + x)$     | 0.980                       |
| 11           | $y = b_0 \cdot e^{b_1/s}$        | 0.985                       |
| 12           | $y = b_0 + b_1 x$                | 1.000                       |

Reliability was defined as the ratio of the number of runs in which the given accuracy of the approximation of the initial data was achieved to the total number of runs. In this case, the maximum number of calculations of the fitness function should not exceed the one specified in the stop criteria. The significance of the runs results was verified by ANOVA technique. The test was performed at a significance level of $\alpha = 0.05$. Obtained results allow drawing a conclusion that the considered usage of the genetic programming method allows achieving high efficiency in solving test problems, which are close to real world problems.

4. Conclusion
The paper considers the problem of flow measurements accuracy improvement under conditions of the usage of vortex flowmeters and proposes a promising direction of increasing accuracy due to the automatic choice of the suitable flowmeter transformation function. The problem can be considered as the symbolic regression problem whose solution should be fine using original data of flow measurements. During our research we use the genetic programming method to select the transformation function of the vortex flowmeter.

To study the effectiveness of the developed approach a number of numerical experiments were performed on a set of problems. Obtained results allow us to introduce the proposed approach for using in similar problems the formulation of which match to the formulation of the problem of symbolic regression. Further direction in the development of the work is the combination of methods for constructing symbolic regression models and algorithms for automatically tuning the numerical parameters of regression models. This will improve the accuracy of the models of the flowmeter conversion function and adapt to the changing environmental conditions in the automatic mode.

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