Investigation of linear models for control of water flow and temperature in a water supply system

Askhat Asset[1], Madina Mansurova[2], Vadim Zhmud[2], Aksholpan Kopesbaeva[1], Nurbolat Dzheksenbaev[2]
[1]Almaty University of Energy and Communications named after G. Daukeev, Almaty, Kazakhstan
[2]Department of AI and Big Data, Al-Farabi Kazakh National University, Almaty, Kazakhstan

Article Info

Article history:

Received Nov 2, 2023
Revised Feb 12, 2024
Accepted Mar 25, 2024

Keywords:

Automation
Control
Modeling
Optimization
Water supply

ABSTRACT

In some cases, the object model is a set of parallel models of the same general appearance, but with different parameters. The most common model is a model in the form of a serial connection of a first- or second-order filter and a delay link. An example is the water supply system of a large residential building or a group of houses. From the most general considerations, we can expect that such an object can be approximately described by a simpler model, replacing the sum of identical-looking models with different parameters with a single model of this type with averaged parameters, however, finding many parameters simply in the form of an average is, apparently, an unreasonable approach. It seems more reasonable to find the parameters by the approximating model by numerical optimization, in which the integral from the module or from the square of the deviation of the output signal of such a model from the output signal of the exact model is minimized when the test signal is applied. For linear models, the most reasonable test signal is a single step effect. This article tests this hypothesis and provides the results of this test.

Corresponding Author:

Askhat Asset
Almaty University of Energy and Communications named after G. Daukeev
Almaty, Kazakhstan
Email: askh.asset@aues.kz

1. INTRODUCTION

The Regulation of the amount and temperature of water supplied to residential buildings is actively used in those places, where there is an acute shortage of water, for example, in certain regions of Kazakhstan. Similar problems may arise in Mongolia, as well as in other Asian and African countries. The reason for this approach is, that it is irrational to carry out large reserves of water in storage tanks, both in connection with the need to save water, and with the complication of the preservation of water in a state that meets sanitary standards when using excessively large tanks. The automatic control system must provide the required water pressure and the required costs, depending on the needs that change throughout the day with some rhythmicity, against which there is also a significant random component. Successful implementation of an automatic regulation system requires knowledge of an accurate model of the water consumption process, which plays the role of a controlled object in this system. But this model consists of many submodels that describe individual consumers, and each consumer has its own random model parameters, and these submodels are non-stationary. In this regard, the legitimate question is how much it is permissible to approximate the set of these submodels with a general model, and to what extent their nonstationarity will affect the stationarity of the integral model as a whole.

The easiest way is to imagine a water supply system as an object of automatic control, in which the output values are the water pressure, and in the case of hot water, also its temperature. The input values in this case will be the water flow rate at the entrance to the water supply system, and in the case of hot water, also the temperature at the entrance to the water distribution system. Also closely related to this problem is the problem of regulating heating, which is provided by the required pressure of warm water and its temperature. Computer modeling of the distribution of water flows in reservoir systems the system of equations of the balance of reservoirs pollution with a constant mixture was obtained and solved. Temporary dynamic concentration of the mixture during and after discharge in three reservoirs, for a certain period of time, filtration through the bottom of the reservoir in non-existent systems has been studied [1].

The ganetxl optimization model for automation of water systems is used, improvement of the correct water distribution is considered and it is shown that epanet2 can be adapted for successful modeling of intermittent water systems, and a set of solutions for economic or social factors is proposed [2]. According to the water distribution and reception system, analytical work was carried out on two different models, in which data was transmitted via global system for mobile communications (GSM) to a database at the receiving station, interfaces and observers were used, and was analyzed on the basis of innovative solutions [3]. Trial work was carried out on two river water resources, water purification was carried out using modern methods to reduce the turbidity phenomenon in several sectors of the river, special sensors for water composition and ph were applied, a comparative analysis of parameters for special samples was carried out [4]. The water supply system provides ways to reduce problems with pipelines during water transportation, to eliminate losses, a “water distribution system based on the Internet of Things” is presented, which is analyzed by “foggy and cloud computing” for water distribution and monitoring the condition of underground pipes. To develop an effective water distribution system based on IoT substances, an analysis of consumer demand was carried out [5].

The analysis of water distribution systems using blockchain innovations in water supply is carried out, and intensive robotization of water supply networks is provided, improved through full reporting and transparency with other developing achievements such as artificial intelligence (AI), machine learning (ML), radio frequency identification (RFID), internet of things (IoT), and near field communication (NFC) [6]. To reduce the need for water, provision of water supply provides for the use of storage water in the presence of stalemate conditions in water supply systems, intelligent household water meters are used when used over continuous water networks. Electromagnetic meters register the flow of water using pulses and provide information about consumption, which gives an idea of the structure of water consumption by volume and time of its use [7]. An accurate understanding of the relationship between the construction of a reservoir and the dynamic change in the water level in the downstream areas provides for the rational development and use of water resources. The interaction between surface waters (SW) and groundwater (GW) is currently being analyzed. The study mainly focuses on the interaction between the river and GW. In these studies, an analysis of the law of change in the water cycle has been carried out and an increase in the coefficient of use of water resources is envisaged [8]. The groundwater level is analyzed as an important factor in the assessment, depending on the set of nonlinear factors for groundwater resources, the modeling of groundwater using a neural network based on theoretical construction models is considered [9]. The methods of improving water quality in water supply are considered, analyzed in the software environment for water resources management based on the developed measures, optimized models to reduce costs in the management of water systems, methods of special operations for water resources management are applied [10]. The tasks and problems of energy saving in water supply systems are considered, optimal water supply of facilities is provided, the use of pumping stations to ensure uninterrupted operation of the water supply system, increasing the dynamic accuracy of control, a proportional-integral-derivative (PID) controller was used when implementing a pressure control system in the water supply networks of the house [11]. The working conditions of a circular damper for regulating the water level are analyzed, dimensionless ratios are given for determining the height of the axis of rotation of a circular shutter based on the depth of water above the flow, and another parameter characterizing the device is the maximum Q_{max} flow rate at which the lid remains closed. When the water flow exceeds Q_{max}, the lid cannot be closed because the water flow into the device exceeds the flow. Changing the position of the Magnet, bringing it closer to the lid, leads to an increase in the closing moment of the lid, which leads to an increase in the water level at which the lid H_0 opens, and a minimum flow of Q_{min}. such problems are considered [12]. According to the dynamic collision of watercourses, a model with a swing of mazels was created, to reduce the size of the modeling zone and the estimated time during modeling, two general types of bridge supports were considered, the research results showed engineers that the water flow velocity and pressure around the bridge support were considered, and the technique proposed in the article significantly increased the accuracy of the calculated force values [13]. The article discusses the development and application of the hydrological model, but a reliable integrated structure, it took into account all relevant components of demand and used an advanced hydroeconomic system to model the distribution of water in the basin [14]. The article provides for optimization in accordance with the requirements for high-pressure submersible hulls, the last best configuration is achieved, For fstw safety coefficients, a value-by-value analysis is developed, the critical pressure value is determined and a comparative analysis is carried out [15]. Analysis of the city's water system, traditional planning of the urban rainwater network, on timely collection and disposal of rainwater from the earth's surface, software interaction models for the implementation of continuous integration with software components are considered [16]. The article shows the use of mathematical modeling to solve a specific problem. Chiang Saen commercial port has been analyzed for water quality problems in its basin during the dry season [17]. Reservoir capacity the main parameter of lakes and reservoirs is considered, and for Speed and ease, an accurate calculation of the capacity of reservoirs of lakes, especially large-area and complex Lakes, is considered, along with which a two-dimensional hydrodynamic model based on the surrounding fluid is considered [18]. In the case of central heating provided by the supply of hot water to the heating system, relay regulators have become widespread, which, if there is an insufficient temperature difference at the inlet and outlet of the coolant, blocks the hot water pressure for a short time. Similar regulators are sometimes installed on hot water, to exclude the supply of water unnecessarily hot, which can lead to burns of users. This sometimes leads to an oscillatory mode, which is also undesirable for users and can even become dangerous, because in this mode, boiling water comes to the user under high pressure from the hot water tap, then drops to almost zero. To manage the facility, it is necessary to take into account that there are a very large number of water and heat consumers in the system, so even if the mathematical model of water consumption by a separate apartment is relatively simple, then taking into account a large number of apartments, the model becomes complex. This article verifies the hypothesis that, what is an object consisting of many identical models with different parameters, it can be approximately described by one similar model, the parameters of which can be calculated, for example, by numerical optimization. In the system of negative feedback, for the purpose of controlling the flow and temperature of water, intelligent solutions for the approximation of several objects and for the study of linear models are considered. The introductory study contextualizes and provides any special information. The information that may be required by the general measurement or control reader is interpreted as a graph, solved by numerical optimization methods that follow this. It has previously been described with reference to the importance of the corresponding ones, in a scientific article the problems solved by the experiment are proved by producing a structured graph to optimize the model approximating the result for several objects and for the target function, which should also reflect the results of your work comparators. In the introduction, the contribution(s) of the article was determined in the form of a specific result and this is shown in the form of a graph in the research section of the article.

2. THE PROPOSED SOLUTION/METHOD

To control the facility, it must be taken into account that there are a very large number of cold and warm water consumers in the system, therefore, the mathematical model of water consumption of an individual apartment is relatively simple, albeit taking into account many apartments, the model will be more complex. This article tests the hypothesis that an object consisting of many identical models with different parameters can be roughly described by a similar model, which can be calculated, for example, by the numerical optimization method. Combining the results in the form of several graphs, different tasks were set on several graphs, and an optimization method was proposed to solve problems.

The sum of a large number of such transmission functions (1) can be approximated by other parameters that are not average parameters of the type transmission function, but, for example, in order to reduce the deviation of the transition process from the transition process at the output of the exact model, an analysis has been made in the literature written earlier, and in my scientific article, a choice is made by quantitative optimization and the result is clearly shown in the form of a graph. This hypothesis needs to be tested by numerical modeling.

Let there be a large number of objects described by a transfer function of the following form:

$$W_i(s) = \frac{k_i}{1+T_i s} e^{-\tau_i s} \tag{1}$$

here W_i – is the Laplace transfer function, s – is the argument of the Laplace transform, i – is the ordinal number of the apartment, is the base of the exponent (the mathematic fundamental constant value e), k_i, T_i, τ_i – are the parameters of the object model with the number i.

It is assumed that the sum of a large number of such transfer functions can be approximated by a transfer function of the form (2).

$$W_{\Sigma}(s) = \sum_{i=1}^{N} W_i(s) = \sum_{i=1}^{N} \frac{k_i}{1+T_i s} e^{-\tau_i s} \approx W_m(s) = \frac{k_m}{1+T_m s} e^{-\tau_m s} \quad (2)$$

Here parameters k_m, T_m, τ_m of the model (2) are not averaged parameters (and not by simple sum of gains). Instead of a statement like:

$$k_m = \sum_{i=1}^{N} k_i,\ T_m = \frac{1}{N}\sum_{i=1}^{N} T_i\ ,\ \tau_m = \frac{1}{N}\sum_{i=1}^{N} \tau_i, \quad (3)$$

it is proposed to find parameters using the method of group numerical optimization in accordance with the relation:

$$\exists\{k_m, T_m, \tau_m\} \leftrightarrow \left| \sum_{i=1}^{N} \frac{k_i}{1+T_i s} e^{-\tau_i s} - \frac{k_m}{1+T_m s} e^{-\tau_m s} \right| \to 0 \quad (4)$$

From general considerations it is clear that for $N \to \infty$ such a solution exists; however, it is important to make sure that such an approximation is also permissible for a finite value of N. It is advisable to find the parameter vector $\{k_m, T_m, \tau_m\}$ using the numerical optimization method. These parameters are calculated not by relation (3), but by an optimization procedure with a target function based on achieving condition (4). A solution to this problem is proposed by numerical optimization to minimize the deviation of the transient process at the output of the approximate model from the transient process at the output of the exact model (2). This hypothesis needs to be verified by numerical simulation.

In this case, it is advisable to use PID controllers or their modification [19]. If successful, it will be possible to use water supply management using a machine-learning program [20] as well as adaptive control methods for a task with many objects [21]. It is also advisable to subsequently use Markov models of this system, as well as carry out mathematical modeling of the activity of object components in real time [22]. In this case, broad prospects for effective monitoring of the water supply system using the methods described in [23] open up. For this purpose, approaches to automation of monitoring described in [24] may be useful.

3. METHOD

For modeling, we use VisSim [25], which can be combined with the MATLAB program and is independent software. This program has the ability to optimize. To use the optimization mode, it is enough to create a model of the system with an object. This is done by the method of graphical programming, that is, standard models from a large list are placed in the working field, which set parameters that can be changed after calling the Edit menu with the right mouse button. Then appropriate connections are inserted between the blocks. Thus, any mathematical model can be easily programmed [26]. There is also an oscilloscope block that displays the calculation result in the form of a graph, and this graph is built in the MATLAB software environment.

The optimization method is one of the most convenient methods for finding the extreme value point of a function, this method has a wide range of applications and is effective in analyzing physical quantities at Waterline levels, reducing the error between all regression and neural network prediction and real data. In comparison with other methods, in this method, judging by the information about quantitative methods of one-dimensional optimization, their role in the construction of quantitative methods of unconditional and conditional minimization is very large, and methods using derivatives and methods of polynomial interpolation are also considered.

The solution to the problem is proposed by the numerical optimization method. For $N = 2$, as well as for $N = 3$, $N = 4$, $N = 5$, we determine the error when controlling using the model on the right side of relation (2) in comparison with the error when controlling using the model on the left side of relation (2). If, as the number N increases, this error drops noticeably, then it is possible to determine the threshold value of the number N, above which an approximation of the form (2) is reliably acceptable. According to the method of mathematical induction, if the error decreases as N increases, it can be stated with a high degree of certainty that there is a threshold value N after which this error is negligible. We will use the optimal values of the parameters$\{k_m, T_m, \tau_m\}$, to find which we use the numerical optimization method. In this case, it is proposed to use the minimization of the integral of the modulus of deviation of the model response from the reaction of the exact object, and as an alternative, the integral of the square of this module [27].

It is also hypothesized that the most difficult case is the approximation by one link of two links of the form (1) with a significant difference in their parameters, especially when the transmission coefficients ki are equal. The more objects of the same nature (but with different coefficients) are included in this sum, the more accurate the approximation can be. This hypothesis is proposed to be tested by modeling in the Vis Sim program. The equality of the gain coefficients in the two links is seen as the worst case, since each of the two links in this case gives the same amplitude contribution to the transient process [28], whereas the discrepancy of the other coefficients will lead to a significant difference in these transients, which will probably make it difficult to solve the problem [29]. The case with negative coefficients is not considered because it does not correspond to any reality in the problem under consideration. At the first step, it is proposed to find the values of the parameters k_m, T_m, τ_m such at which the minimum difference of a certain target control function Ψ is ensured using this model:

$$\{k_m, T_m, \tau_m\} \to \min\{|\Psi\left[\frac{k_m}{1+T_m s}e^{-\tau_m s}\right] - \Psi\left[\sum_{i=1}^{N}\frac{k_i}{1+T_i s}e^{-\tau_i s}\right]|\} \tag{5}$$

We will supply the same input signals to the input of both models both in the left part (2) and in the right part of equation (2), namely: a unit step jump. Let the output of the equivalent model standing on the left side of this equation form the process $U_m(t)$, and the output of the sum of the models standing on the right side of equation (2) form the signal $U_\Sigma(t)$. In this case, the objective function, the minimum of which will be found during optimization, has the following view:

$$\Psi_1 = \int_0^T |U_m(t) - U_\Sigma(t)| dt \tag{6}$$

here T – is the integration time of the process. Another variant of the objective function has the following form:

$$\Psi_2 = \int_0^T |U_m(t) - U_\Sigma(t)|^2 dt \tag{7}$$

Also, for optimization, the cost function calculation unit (5) with elements (6) and (7) must be programmed in the same way. The output of this block is connected to the input of the "value" block, and the input of this block is connected to the output of the quantities added to the coefficients (5)-(7). Also, blocks "unknown parameters" are used, the number of which corresponds to the number of parameters that must be found by the numerical optimization method. Initial values are given to the inputs of these blocks; for example, all zero values can be given if there is no basis for starting optimization from other initial values [30]. The output of these blocks is transmitted to the bus blocks, which are given names according to the designations of optimized quantities. So that these quantities can be used in modeling, the same names must be used in the model of the system. This optimization method is described in detail, for example, in publications [31].

Figure 1 shows a scheme for solving the problem by numerical optimization for an objective function of the form (6). Here the initial values of the two transfer functions are taken as follows:

$$W_1(s) = \frac{1}{1+s}e^{-s} \tag{8}$$

$$W_2(s) = \frac{1}{1+2s}e^{-4s} \tag{9}$$

the mathematical model of the approximating link has the following form:

$$W_{m1}(s) = \frac{2.0567}{1+2.87043s}e^{-1.3116s} \tag{10}$$

The graph on the right side of Figure 1 shows three processes: the process at the output of the total object (line 2), the process at the output of the approximating model (line 1) and the difference between these two processes, that is, the approximation error (line 3) [32].

Figure 2 shows the structure for optimization and the result of optimization by the objective function of the form (6). As a result of optimization, the following approximating model is obtained:

$$W_{m2}(s) = \frac{2.22672}{1+4.29653s}e^{-0.774595s} \tag{11}$$

It is possible by comparing the graphs in Figures 1 and 2 to assert, what is the criterion in the form of an objective function (6) based on the integral of the square of the error, it is more effective because in this case the maximum error becomes less [33], in this case it is a value of 0.2 units (10%), achieved only once, whereas when using criterion (7), the maximum error is 0.3 units (15%) and this value is achieved twice. It is also hypothesized that the more objects participate in the sum, the smaller the relative approximation error will be. To test this hypothesis, modeling was carried out with the number of object models equal to three and four [34].

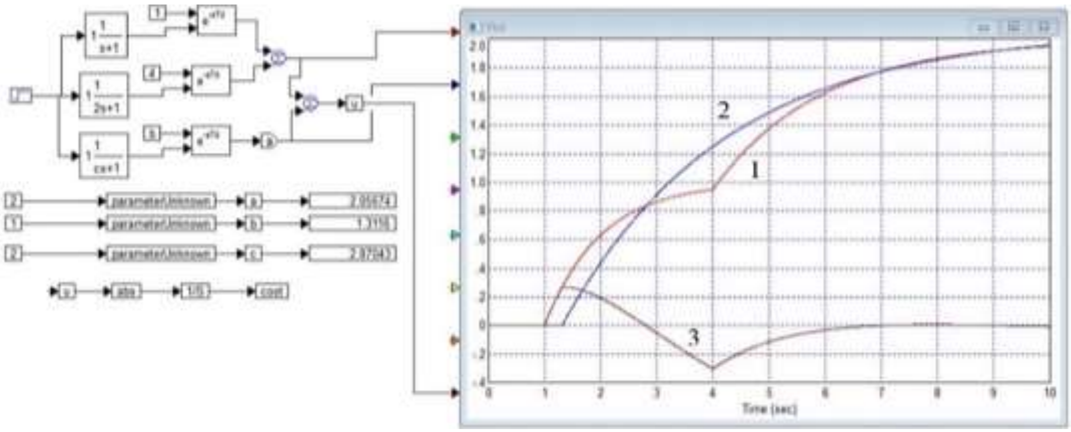

Figure 1. Structure for optimizing the approximating model (2) for objects (8) and (9) for the objective function (6) with the result (10)

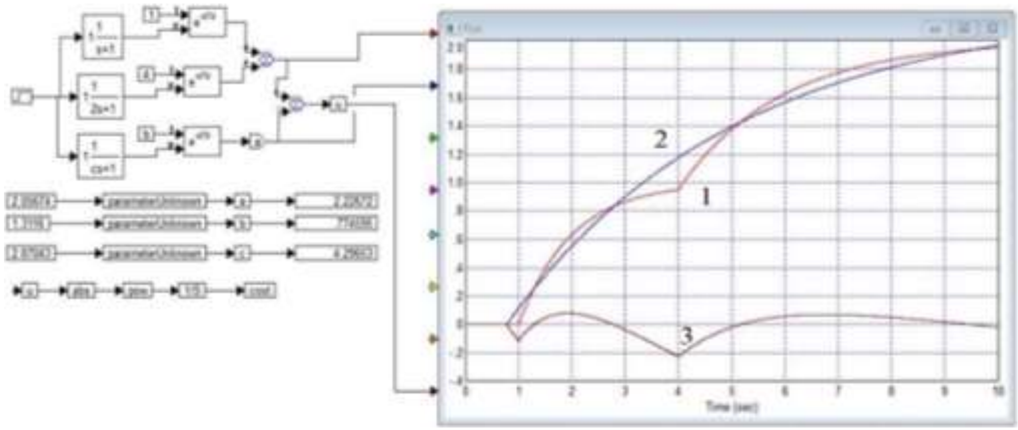

Figure 2. Structure for optimizing the approximating model (2) for objects (8) and (9) for the objective function (7) with the result (11)

Figure 3 shows the scheme for modeling and the result when using three models [35]. At the same time, the most remote location of the lag time constants was also chosen, namely: almost exponentially, and the transmission coefficient of each link was taken equal to one, since with the same coefficients of the models, the contribution of each model is the same, therefore, the most different effects from each model are achieved. It is obvious that, for example, if the coefficient of the transfer function of one of the objects is an order of magnitude smaller than all the others, then this function will have less impact. The values used were $k_1 = k_2 = k_3 = 1$, $T_1 = 1$, $T_2 = T_3 = 2$, $\tau_1 = 1$, $\tau_2 = 4$, $\tau_3 = 8$. The resulting graphs are shown in the right part of Figure 3. The values of the approximating transfer function found have the following values: $k_m = 3.36853$, $T_m = 7.0078$, $\tau_m = 0.952$. Thus, the model of the approximating model has the following form:

$$W_{m3}(s) = \frac{3.36853}{1+7.0078s} e^{-0.952s} \quad (12)$$

Note that the maximum error value in this case is approximately 0.2 units, which is 0.067%. However, it can be noted that in this experiment it is advisable to increase the simulation time in order to get a better approximation, since it is clear that the error increases in magnitude at the end of the graph. By the value of the coefficient of the resulting transfer function, it can be seen that it differs from the value of the sum of all the coefficients of the elements included in all models, which are summed up in the exact model. The difference is about 12%, this will give a static error. The same can be said about the results shown in Figure 2 earlier, where the static error will be 11%. The result shown in Figure 1 has a smaller static error, which is only 2.5%. It is obvious that if the simulation time increases, the static error will decrease down to zero, but the dynamic error may increase slightly. In the next series of experiments, several hypotheses were tested. Firstly, the hypothesis that with a larger number of objects, the approximation error will decrease. Secondly, the hypothesis that the greatest approximation error will be in the case of approximately the same filter time constants. Thirdly, as the simulation time increases during optimization, the optimization error will decrease, including the static error.

The results shown in Figure 4-6 confirm the validity of all these hypotheses [36]. Indeed, Figure 4 shows the scheme for optimization and the result for the case with four models included in the sum. In this case, not only the lag time constants are taken approximately exponentially, but also the filter time constants. Namely: $k_1 = k_2 = k_3 = k_4 = 1$, $T_1 = 1$, $T_2 = 2$, $T_3 = 4$, $T_4 = 12$, $\tau_1 = 1$, $\tau_2 = 4$, $\tau_3 = 8$, $\tau_3 = 14$. In this case, the maximum error is 0.2 units, i.e. 0.05%. At the same time, the static error is 2.5%, what can be determined by the difference in the transmission coefficient of the approximating model from the sum of all transmission coefficients in all models included in the object. This confirms the first hypothesis.

Figure 5 shows similar results for the case when the time constants of all filters in all models are the same and equal to one: $T_1 = T_2 = T_3 = T_4 = 1$. In this case, the maximum error reaches 0.4 units, i.e. twice as much as in the previous experiment. The static error *is* 7.5%. This confirms the second hypothesis [37]. Figure 6 shows similar results when the experiment time is doubled [38]. The maximum error value has slightly increased and reached a peak value of 0.5 units, but the static error has sharply decreased and is 1.3%.

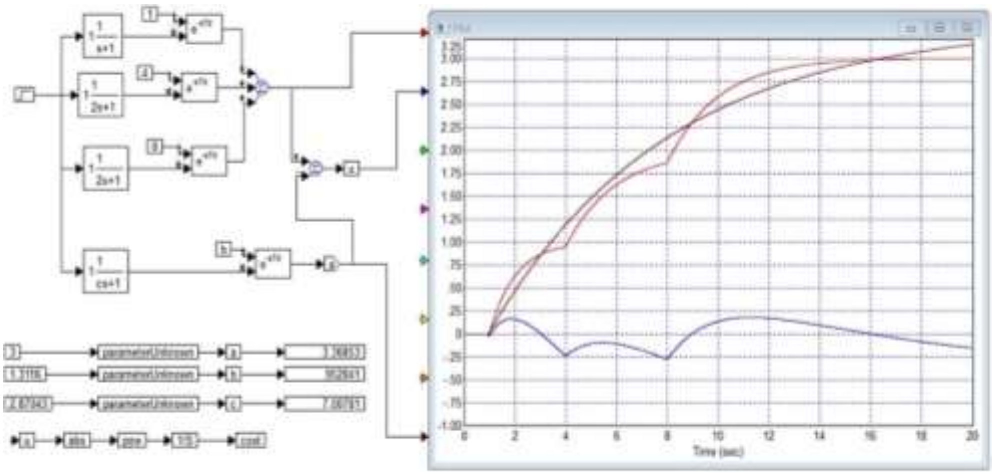

Figure 3. Structure for optimizing the approximating model (2) for $N = 3$ and for the objective function (6)

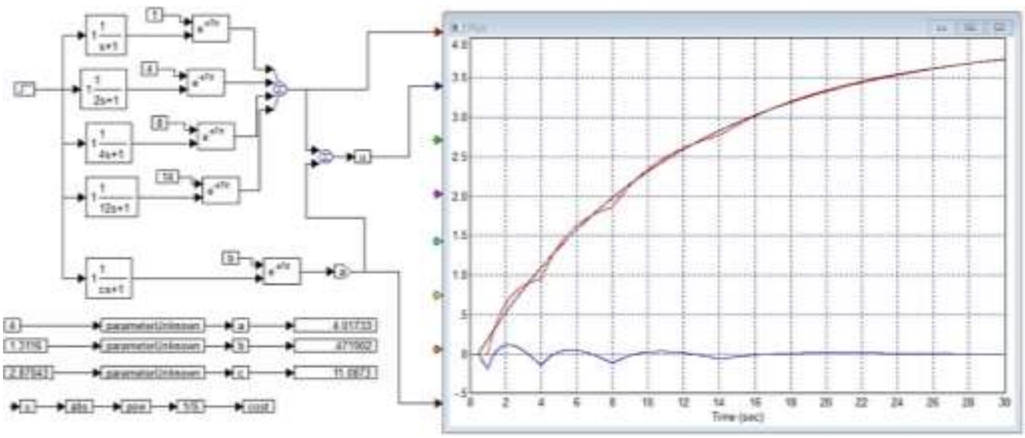

Figure 4. Structure for optimizing the approximating model (2) for $N = 4$ and for the objective function (6) at different values of the filter time constant in the summarized models

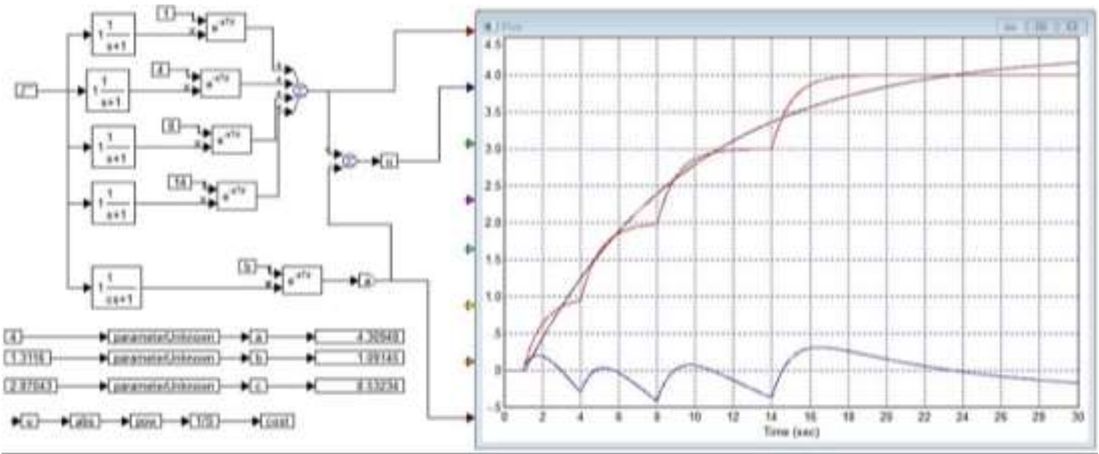

Figure 5. Structure for optimizing the approximating model (2) for N = 4 and for the objective function (6) with the same values of the filter time constant in the summarized models

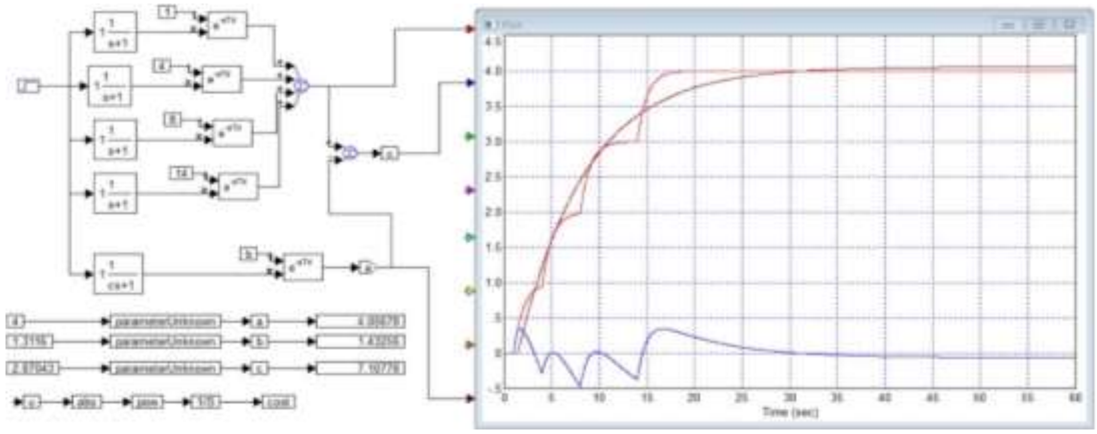

Figure 6. The same, what is shown in Figure 5 when the experiment time is doubled

In the second case, shown in Figure 6, the static approximation error is reduced. If in Figure 5 the error continues to increase after the end of the simulation time, then in Figure 6 the error reaches a smaller value and after that does not increaseи [38]. Let us show that the obtained values differ from the values that could be obtained from relations (3). Indeed, for this model $k_m = 4.05678, T_m = 7.10778, \tau_m = 1.43256$, while calculations using relation (3) would give the following values: $k_m = 4$, $T_m = 1, \tau_m = 6.75$. Thus, this article not only proves the assumption that such an approximation is possible, but also provides a method for calculating the coefficients of this approximation.

A detailed description of the problem posed in the scientific article was proposed to be solved by a quantitative method, that is, a different model was created in this article when compared to other researchers using the Vis Sim program, in this model, it is necessary to reduce the Integral from the module of the deviation of the reaction from the reaction of the real object, and it is also proposed to use as an alternative, with the help of the program, several models are compared in several ways according to the structure. Unlike other researchers, this article used the method of quantitative optimization. When creating a model with the selection of devices and regulators in the water system, an experiment was carried out, Mathematical modeling has reliably confirmed that the mathematical model of many objects with random values of the parameters of the model can be replaced with a simple model. In the analysis of data and solutions to exclude some data and add others during the experiment, several samples were constructed to optimize the approximation model for the target function, and it was found in detail that the approximation error decreases to 10% or less at N = 3.

4. RESEARCH AND DISCUSSION

Mathematical modeling has reliably confirmed that the mathematical model of many objects with random values of the parameters of the model can be replaced by a simple model. The experiment found that the error of such an approximation drops to 10% or less at N = 3. In the case of a large variance of the Ti and ti parameters, the approximation error can be reduced to 2-3%, the largest error occurs when the values of the ki and Ti parameters coincide, and the largest mismatch of the values of the Ti parameter. Regarding the water supply problem to be solved, the ti value depends on the length of the supply pipes, and the ki value is determined by the intensity of water consumption, the Ti value has the least dispersion, since it is determined by the opening and closing speed of the valves. The information obtained made it possible to accurately simulate the operation of the water system by many users. This scientific paper made it possible to find the most adequate aggregate model of the users of the system by collecting statistics on the water distribution station based on reactions to small test effects when compared to previously written articles, which were then used to optimize the regulator in this system.

5. CONCLUSION

As for the summary of the problem based on the results of the experiment conducted by the vis sim program in this article, taking into account the problems in the articles previously considered on this topic, in order to control the flow and temperature of water in a negative feedback system, linear models for approximating several objects were developed, a literature review was made with brief reference to the main ones, the main participants created several different models on several objects, the main participants experimented on the results of the models, unresolved problems and/or directions that need. The article proves using mathematical modeling that the more objects are included in the system, the more accurately the approximation of this model can be carried out by a simpler link, consisting not of a set of models, but of one model. A method for calculating the parameters of this model, which differs from simple averaging, has been developed and justified. It is shown that the worst case is the sum of models with approximately the same coefficients and time constants of filters, the difference between my article compared to previous written articles is that in both models the error does not exceed 12%, and with an increase in the number of simple models included in the system, this error decreases sharply.

REFERENCES

[1] P. Eswaran and A. Kumar, "Conceptual design and development of water metering system for multiple family residential buildings," *International Journal of Advanced Computer Research Preview publication details*, vol. 2, no. 4, pp. 501–505, 2012.

[2] E. E. Ameyaw, F. A. Memon, and J. Bicik, "Improving equity in intermittent water supply systems," *Journal of Water Supply: Research and Technology-Aqua*, vol. 62, no. 8, pp. 552–562, Dec. 2013, doi: 10.2166/aqua.2013.065.

[3] S. B. Chandanapalli, E. S. Reddy, and D. R. L. Davuluri, "Efficient design and deployment of aqua monitoring systems using WSNs and correlation analysis," *International Journal of Computers Communications & Control*, vol. 10, no. 4, p. 471, Aug. 2015, doi: 10.15837/ijccc.2015.4.1514.

[4] D. Perdana, J. Naufal, and I. Alinursafa, "Performance evaluation of river water quality monitoring using lora connectivity with fuzzy algorithm," *International Journal of Computers Communications & Control*, vol. 16, no. 4, pp. 1–13, Jul. 2021, doi: 10.15837/ijccc.2021.4.4226.

[5] L. K. Narayanan, S. Sankaranarayanan, J. J P C Rodrigues, and S. Kozlov, "Water demand forecasting using deep learning in IoT enabled water distribution network," *International Journal of Computers Communications & Control*, vol. 15, no. 6, Nov. 2020, doi: 10.15837/ijccc.2020.6.3977.

[6] E. Sriyono, "Digitizing water management: toward the innovative use of blockchain technologies to address sustainability," *Cogent Engineering*, vol. 7, no. 1, p. 1769366, Jan. 2020, doi: 10.1080/23311916.2020.1769366.

[7] C. David, M. García, and C. J. Navarro Gómez, "Analysis of hybrid demand pattern on a water distribution network with transition from intermittent to continuous water supply in Riberas de Sacramento, Chihuahua," *Water Practice and Technology*, vol. 15, no. 1, pp. 213–224, Mar. 2020, doi: 10.2166/wpt.2020.013.

[8] J. Zhang *et al.*, "Impact of mountain reservoir construction on groundwater level in downstream loess areas in Guanzhong basin, China," *Water*, vol. 14, no. 9, p. 1470, May 2022, doi: 10.3390/w14091470.

[9] Jian Zhang and Yuansheng Lou, "Water level prediction based on improved grey RBF neural network model," in *2016 IEEE Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC)*, IEEE, Oct. 2016, pp. 775–779. doi: 10.1109/IMCEC.2016.7867315.

[10] F. Teng and Q. Liu, "Robust multiple ship tracking in inland waterway CCTV system," *TELKOMNIKA Indonesian Journal of Electrical Engineering*, vol. 12, no. 11, Nov. 2014, doi: 10.11591/telkomnika.v12i11.6030.

[11] A. M. Kulia, "Automation of the residential building water supply system pumping station," *Automation of technological and business processes*, vol. 8, no. 2, Aug. 2016, doi: 10.15673/atbp.v8i2.165.

[12] J. Kubrak, E. Kubrak, E. Kaca, A. Kiczko, and M. Kubrak, "Theoretical and experimental analysis of operating conditions of a circular flap gate for an automatic upstream water level control," *Water*, vol. 11, no. 12, 2019, doi: 10.3390/w11122576.

[13] L. Nguyen-Ngoc *et al.*, "Smoothed particle hydrodynamics simulation and evaluation of water flow pressure on bridge piers," *Journal of Applied Science and Engineering (Taiwan)*, vol. 26, no. 10, 2023, doi: 10.6180/jase.202310_26(10).0012.

[14] D. Xu, "A hybrid hydro-economic framework to allocate water over the basin scale region under water shortage period," *Journal of Applied Science and Engineering (Taiwan)*, vol. 27, no. 1, pp. 1843–1858, 2024, doi: 10.6180/jase.202401_27(1).0001.

[15] H. M. Waqas, D. Shi, M. Imran, S. Z. Khan, E. Fathallah, and M. Helal, "Design optimization of composite wood sandwiched submersible pressure hulls," *Journal of Applied Science and Engineering (Taiwan)*, vol. 26, no. 9, pp. 1295–1304, 2023, doi: 10.6180/jase.202309_26(9).0010.

[16] D. Liu and J. Liu, "Intelligent planning of rain water drainage system in new urban areas considering the planning of road network," *Journal of Applied Science and Engineering*, vol. 22, no. 2, pp. 315–328, 2019, doi: 10.6180/jase.201906_22(2).0013.

[17] C. Saengsupavanich, "Enhancing water circulation in a river port," *Journal of Applied Science and Engineering*, vol. 22, no. 1, pp. 39–48, 2019, doi: 10.6180/jase.201903_22(1).0005.

[18] L. Li, G. Y. Lai, and P. Wang, "Study on the dynamic correlation between water-level and reservoir capacity of poyang lake based on EFDC," *Journal of Applied Science and Engineering*, vol. 19, no. 4, pp. 413–428, 2016, doi: 10.6180/jase.2016.19.4.05.

[19] M. Md Ghazaly, S. P. Tee, and N. Zainal, "Anti-windup modified proportional integral derivative controller for a rotary switched reluctance actuator," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 12, no. 6, pp. 3311–3324, Dec. 2023, doi: 10.11591/eei.v12i6.6027.

[20] M. Baniyounis, S. Z. Salah, and J. A. Ghaeb, "Machine learning for prediction models to mitigate the voltage deviation in photovoltaic-rich distributed network," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 13, no. 1, p. 55, Feb. 2023, doi: 10.11591/ijece.v13i1.pp55-68.

[21] I. Moumen, J. Abouchabaka, and N. Rafalia, "Adaptive traffic lights based on traffic flow prediction using machine learning models," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 13, no. 5, p. 5813, Oct. 2023, doi: 10.11591/ijece.v13i5.pp5813-5823.

[22] K. Maaloul, L. Brahim, and N. M. Abdelhamid, "Real-time human activity recognition from smart phone using linear support vector machines," *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 21, no. 3, pp. 574–583, 2023, doi: 10.12928/TELKOMNIKA.v21i3.24100.

[23] R. Ponnala, M. Chakravarthy, and S. V. N. L. Lalitha, "Effective monitoring of power system with phasor measurement unit and effective data storage system," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 11, no. 5, pp. 2471–2478, 2022, doi: 10.11591/eei.v11i5.4085.

[24] M. Safii, S. Efendi, M. Zarlis, and H. Mawengkang, "Intelligent evacuation model in disaster mitigation," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 11, no. 4, pp. 2204–2214, 2022, doi: 10.11591/eei.v11i4.3805.

[25] M. Maiolo, M. Carini, G. Capano, D. Pantusa, and M. Iusi, "Trends in metering potable water," *Water Practice and Technology*, vol. 14, no. 1, pp. 1–9, Mar. 2019, doi: 10.2166/wpt.2018.120.

[26] T. Capt, A. Mirchi, S. Kumar, and W. S. Walker, "Urban water demand: statistical optimization approach h to modeling daily demand," *Journal of Water Resources Planning and Management*, vol. 147, no. 2, Feb. 2021, doi: 10.1061/(ASCE)WR.1943-5452.0001315.

[27] L. G. Valdiviezo Gonzales, F. F. García Ávila, R. J. Cabello Torres, C. A. Castañeda Olivera, and E. A. Alfaro Paredes, "Scientometric study of drinking water treatments technologies: Present and future challenges," *Cogent Engineering*, vol. 8, no. 1, Jan. 2021, doi: 10.1080/23311916.2021.1929046.

[28] V. A. Zhmud, L. V. Dimitrov, and H. Roth, "A new approach to numerical optimization of a controller for feedback system," *DEStech Transactions on Engineering and Technology Research*, no. ameme, Dec. 2017, doi: 10.12783/dtetr/ameme2017/16224.

[29] V. Zhmud, O. Yadrishnikov, A. Poloshchuk, and A. Zavorin, "Modern key techologies in automatics: structures and numerical optimization of regulators," in *2012 7th International Forum on Strategic Technology (IFOST)*, IEEE, Sep. 2012, pp. 1–4. doi: 10.1109/IFOST.2012.6357804.

[30] V. Zhmud, A. Liapidevskii, and B. Pyakillya, "Numerical optimization of PID-regulator for object with distributed parameters," *Journal of Telecommunication, Electronic and Computer Engineering*, vol. 9, no. 2–3, pp. 9–14, 2017.

[31] V. Zhmud, A. Liapidevskiy, and E. Prokhorenko, "The design of the feedback systems by means of the modeling and optimization in the program VisSim 5.0/6," in *Modelling, Identification, and Control*, Calgary,AB,Canada: ACTAPRESS, 2010. doi: 10.2316/P.2010.702-018.

[32] Y.-P. Lin, J. Petway, W.-Y. Lien, and J. Settele, "Blockchain with artificial intelligence to efficiently manage water use under climate change," *Environments*, vol. 5, no. 3, p. 34, Feb. 2018, doi: 10.3390/environments5030034.

[33] X. Litrico, G. Belaud, J.-P. Baume, and J. Ribot-Bruno, "Hydraulic modeling of an automatic upstream water-level control gate," *Journal of Irrigation and Drainage Engineering*, vol. 131, no. 2, pp. 176–189, 2005, doi: 10.1061/(asce)0733-9437(2005)131:2(176).

[34] S. J. Mohammed, S. L. Zubaidi, S. Ortega-Martorell, N. Al-Ansari, S. Ethaib, and K. Hashim, "Application of hybrid machine learning models and data pre-processing to predict water level of watersheds: recent trends and future perspective," *Cogent Engineering*, vol. 9, no. 1, Dec. 2022, doi: 10.1080/23311916.2022.2143051.

[35] A. Poberezhna, "Addressing water sustainability with blockchain technology and green finance," in *Transforming Climate Finance and Green Investment with Blockchains*, Elsevier, 2018, pp. 189–196. doi: 10.1016/B978-0-12-814447-3.00014-8.

[36] R. Ranjbar and A. H. Abdalla, "Development of an autonomous remote access water quality monitoring system," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 8, no. 2, pp. 467–474, 2017, doi: 10.11591/ijeecs.v8.i2.pp467-474.

[37] D. Donnelly, "The fast fourier and hilbert-huang transforms: a comparison," *International Journal of Computers Communications & Control*, vol. 1, no. 4, p. 45, 2006, doi: 10.15837/ijccc.2006.4.2305.

[38] T. Deepiga and M. A. Sivasankari, "Smart water monitoring system using wireless sensor network at home / office," *International Research Journal of Engineering and Technology*, vol. 02, no. July 2015, pp. 1305–1314, 2015.

BIOGRAPHIES OF AUTHORS

Askhat Asset Almaty University of Energy and Communications named after G. Daukeev, Almaty, 050013, Kazakhstan, Senior lecturer Department "automation and control". Almaty University of Energy and Communications named after G. Daukeev,2013-1016 worked as an engineer of "control and automation of measuring instruments" Seg LLP Almaty, Kazakhstan. He can be contacted at email: askh.asset@aues.kz.

Madina Mansurova Research interests in the areas of high-performance computing, MapReduce, MPI technologies, natural language processing, artificial intelligence, intelligent control systems and mathematical and computer modeling. Supervisor of grant funding projects with the support of the Ministry of Higher Education and Science of the Republic of Kazakhstan. Author of more than 70 scientific publications in ranking journals and proceedings of international conferences. Affiliation: Al-Farabi Kazakh National University, Almaty, 050040, Kazakhstan, Associate Professor, Candidate of Physical and Mathematical Sciences, Associate Professor. Faculty of Information Technologies, Head of the Department "Artificial Intelligence and Big Data". Almaty, Kazakhstan. She can be contacted at email: madina.mansurova@kaznu.kz.

Vadim Zhmud Al-Farabi Kazakh National University, Almaty, 050040, Kazakhstan, Professor, Doctor of technical sciences, Almaty, Kazakhstan. He received his PhD for the development of electronic components for laser Doppler hot-roll speed and length meters. His scientific degree of Doctor of Technical Sciences was awarded for work related to the development and implementation of electronic systems for controlling laser radiation, including the introduction of semiconductor lasers as coherent radiation sources in laser spectroscopy. Main areas of interest: automation, mathematical modeling, optimization, laser physics, photonics, optoelectronics. He is a member of the editorial board of 12 international journals. He can be contacted at email: vadim.zhmud@kaznu.kz.

Aksholpan Kopesbaeva Almaty University of Energy and Communications named after G. Daukeev, Almaty, 050013, Kazakhstan, Professor of the Department "automation and control" of the Almaty University of energy and Communications named after G. Daukeev, candidate of technical sciences. Almaty, Kazakhstan. She can be contacted at email: a.kopesbayeva@aues.kz.

Nurbolat Dzheksenbaev Al-Farabi Kazakh National University, Almaty, 050040, Kazakhstan, Senior Lecturer, Candidate of Technical Sciences. He can be contacted at email: nurbolat.dzhexenbaev@kaznu.edu.kz.