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122 КОМП'ЮТЕРНІ НАУКИ ТА ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ

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MATHEMATICAL MODEL FOR ASSESSING THE FUNCTIONAL STATE OF HUMAN EYE PARAMETERS

Mathematical models of the human eye's condition should serve as adaptive tools for analyzing and predicting ophthalmological parameters, considering their interactions and individual patient characteristics. Such models are in high demand in ophthalmology because they improve the diagnosis, monitoring, and treatment of diseases, thereby enhancing patients' quality of life. The key aspects of the developed mathematical model of the human eye's condition include its structure and functionality, based on a mathematical function that integrates the eye's physiological parameters, with each parameter assigned a weight coefficient that determines its contribution to the integral indicator of the eye's condition. The model accounts for complex nonlinear interactions between parameters, reflecting the intricacies of physiological processes. To optimize weight coefficients, the L-BFGS-B method is employed, an iterative optimization technique that effectively minimizes the loss function, ensuring high accuracy and adaptation of the model to individual patient data. The advantages and applications of this model include accurate diagnosis by enabling the early detection of diseases such as glaucoma, cataracts, and macular degeneration; personalized treatment through a tailored approach that considers the unique parameter values of each patient; monitoring and prediction capabilities for analyzing disease progression and facilitating treatment adjustments in early stages; and integration with technologies, offering potential applications in virtual and augmented reality systems and artificial intelligence frameworks for automating diagnostics. The developed model serves as a universal tool for analyzing the eye's condition and creating new diagnostic and treatment technologies. It considers the interrelations between parameters and their influence on the physiological state of the eye, providing professionals with a powerful instrument for advancing ophthalmological practice.
Keywords: *human eye, mathematical model, integral indicator, nonlinearity, optimization, adaptation, monitoring, prediction.*

Вичужанін В., Вичужанін А., Гузун О., Задорожний О. Математична модель для оцінки функціонального стану параметрів людського ока. *Математичні моделі стану людського ока повинні бути адаптивними інструментами для аналізу та прогнозування офтальмологічних параметрів з урахуванням їх взаємодій та індивідуальних особливостей пацієнта. Такі моделі затребувані в офтальмології, оскільки вони покращують діагностику, моніторинг та лікування захворювань, підвищуючи якість життя пацієнтів. Ключовими аспектами розробленої математичної моделі стану ока є її структура та функціональність. Вона заснована на математичній*

[1] *doctor of technical sciences, professor, Odesa Polytechnic National University, Odessa, ORCID: 0000-0002-6302-1832, v.v.vychuzhanin@op.edu.ua*
[2] *Ph.D. in computer science, assistant professor, Odesa Polytechnic National University, Odessa, ORCID: 0000-0001-8779-2503, vychuzhanin.o.v@op.edu.ua*
[3] *candidate of medical sciences, SI «The Filatov Institute of Eye Diseases and Tissue Therapy of the National Academy of Medical Sciences of Ukraine», Odessa, ORCID: 0009-0003-6873-8503, olga.v.guzun@gmail.com*
[4] *doctor of medical sciences, SI «The Filatov Institute of Eye Diseases and Tissue Therapy of the National Academy of Medical Sciences of Ukraine», Odessa, ORCID: 0000-0003-0125-2456, zadoroleg2@gmail.com*

функції, яка інтегрує фізіологічні параметри ока, причому кожному параметру надається ваговий коефіцієнт, що визначає його внесок у інтегральний показник стану ока. Модель враховує складні нелінійні взаємодії між параметрами, що відбивають тонкощі фізіологічних процесів. Для оптимізації вагових коефіцієнтів застосовується метод L-BFGS-B – ітеративний метод оптимізації, що ефективно мінімізує функцію втрат, що забезпечує високу точність та адаптацію моделі до індивідуальних даних пацієнта. Переваги та застосування цієї моделі включають точну діагностику, що дозволяє виявляти такі захворювання, як глаукома, катаракта або макулярна дегенерація на ранніх стадіях; персоналізоване лікування завдяки врахуванню унікальних значень параметрів кожного пацієнта; моніторинг та прогнозування, що забезпечують аналіз прогресування захворювань та допомагають коригувати лікування на ранніх стадіях; інтеграцію з технологіями, включаючи можливості застосування у системах віртуальної та доповненої реальності, а також у рамках штучного інтелекту для автоматизації діагностики. Розроблена модель є універсальним інструментом для аналізу стану ока та розробки нових технологій діагностики та лікування. Вона враховує взаємозв'язки параметрів та їх вплив на фізіологічний стан ока, надаючи офтальмологам потужний інструмент для покращення діагностики, прогнозування та моніторингу очних захворювань.

Ключові слова: *людське око, математична модель, інтегральний показник, нелінійність, оптимізація, адаптація, моніторинг, прогнозування.*

Description of the problem. Mathematical models of the eye play a pivotal role in ophthalmology, offering effective IT solutions for the early diagnosis, monitoring, and treatment of eye diseases [1-3]. Key applications include:

- Early Diagnosis: Algorithms enable automated detection of diseases at early stages, facilitating timely medical intervention;
- Condition Monitoring: Systems track the progression of chronic diseases and assess treatment efficacy;
- Personalized Treatment: Adaptive models support therapy selection tailored to the unique characteristics of each patient;
- Improved Procedural Accuracy: Models aid in planning surgical interventions, reducing risks and enhancing outcomes;
- Scientific Research: Analysis of eye-related biological processes informs the development of innovative treatments;
- Cost Reduction: Optimized diagnostic and treatment workflows minimize unnecessary procedures, lowering overall expenses.

Models that incorporate parameters such as intraocular pressure, visual field index, and perfusion pressure enable highly accurate risk prediction for glaucoma and other pathologies. The integration of machine learning algorithms enhances the personalization and efficiency of diagnostics, providing advanced IT solutions to improve the quality of ophthalmic care.

Analysis of the latest research and publications. A review of the literature on mathematical models for the human eye highlights several areas of application relevant to both ophthalmology and IT specialists:

1. Vision Diagnosis and Correction: Models provide personalized treatment approaches and high diagnostic precision, particularly for visual anomalies and accommodation analysis. Challenges include the need for high-quality data and expert interpretation [4, 5];
2. Retinal Disease Prediction: Models predicting retinal pathologies enhance diagnosis and treatment but require standardized datasets and solutions for interpretability challenges [6, 7];
3. Simulation of Visual Processes: Models of eye-brain interactions are utilized for diagnosing vision impairments and advancing computer vision technologies. Limitations include computational demands and difficulties in generalization [8, 9];
4. Vision Correction and Restoration: Laser vision correction models improve procedural safety, though constraints arise from the complexity of biological processes and computational requirements [10];

5. Age-Related Vision Changes: Models analyzing age-related changes support early diagnosis and individualized treatment but depend on accurate data for diverse age groups and advanced biological methods [10, 11];

6. VR/AR Technologies: Integration with VR/AR improves diagnostics and treatment but faces high computational requirements and adaptation challenges [9];

7. Eye Movement Dynamics: These models are critical in medicine and VR/AR applications, with increasing effectiveness supported by advances in machine learning and accuracy improvements [9];

8. Intraocular Pressure and Heat Transfer Models: Such models predict diseases and enable personalized treatments, though they require validation and better-quality input data [12-15];

The development of a universal mathematical eye model that incorporates a wide range of factors remains a pressing task. These models hold potential for integrating diverse data to enhance the diagnosis, prediction, and treatment of ophthalmological diseases.

Purpose and task statement. The purpose of creating a mathematical model of the human eye is to provide informational support for the diagnosis and prediction of eye conditions.

Achieving this goal requires the development of an adaptive tool that considers a wide range of factors influencing the health and functionality of the eye. The development of a new mathematical model for the eye involves solving a set of tasks related to accounting for numerous interrelated factors. The model must be flexible, integrating structural and functional parameters, including nonlinear changes, the influence of physiological and external factors, and the ability to adapt to individual characteristics of a person. Ultimately, such a model will contribute to improving the diagnosis and treatment of eye diseases and enhancing people's quality of life.

Summary of the main material. The developed mathematical model of the human eye is presented as an integral indicator of its condition (S_{eye}), where the integral indicator S_{eye} is calculated considering the nonlinearity of parameters and their interconnections, the weight of each parameter, and changes influenced by the patient's age, blood flow, and other factors. The S_{eye} model describes the eye's condition as a function of key parameters:

$$S_{eye} = k1 \cdot log(IOP + 1) + k2 \cdot log(RQ + 1) + k3 \cdot (BCVA - h)^2 + k4 \cdot log(Tr + 1) + \quad (1)$$
$$+k5 \cdot e^{-VF1} + k6 \cdot log(1 + Pperf) + k7 \cdot log(1 + \alpha/t1\,) + k8 \cdot log(age + 1) + +k9 \cdot$$
$$\cdot\, e^{eadditional\_factor},$$

where *IOP* - intraocular pressure (maintains eye tone and supports normal functioning), measured in mmHg, normal range: 10-21 mmHg (possible variation: 5-60 mmHg);

RQ - volumetric intraocular blood flow (reflects the volume of intraocular circulation), normal range: 3.2-3.5 ‰ (possible variation: 0.5-9.0%);

BCVA - best corrected visual acuity, normal: 1.0 (possible variation: 0-2.0);

Tr - tear production, measured in mm, normal range: 10-30 mm (possible variation: 1.0-40.0 mm);

VFI - visual field index, normal value: 100%;

Pperf - perfusion pressure (supports blood supply to the eye tissues), normal range: 55-80 mmHg (possible variation: 20.0-100.0 mmHg);

α/t1 - tone of intraocular vessels, normal range: 18-20% (possible variation: 12.0-35.0%), where α is the autoregulation coefficient;

age - the person's age;

additional_factor - an additional factor (lifestyle, diseases, genetic traits, etc.);

k1 ... k9 - weighting coefficients.

Parameters such as *IOP*, *RQ*, *BCVA*, and *VFI* fluctuate within their normal ranges, yet their variations can significantly impact the overall state of the eye [16]. *Tr*, *IOP*, and *Pperf* are critical for maintaining intraocular pressure and adequate blood supply. Age and additional factors can modify various parameters, influencing their weight within the model. Each parameter in the model is interrelated through equations:

1. $IOP \leftrightarrow Pperf : Pperf = Psystolic - IOP.$

At high *IOP*, the perfusion pressure decreases, reducing the blood supply to the eye, thereby increasing the risk of glaucoma;

2. $IOP \leftrightarrow RQ : RQ \propto Pperf \propto Psystolic - IOP.$

The effect of high *IOP* leads to unstable ocular blood flow, which results in ischemia and damage to the optic nerve;

3. $Pperf \leftrightarrow RQ : RQ = k \cdot Pperf^n$,

where *n* is an empirical parameter (usually *n*=1 or *n*<1).

When *Pperf* decreases (for example, due to high *IOP* or low blood pressure), blood flow decreases;

4. $BCVA \leftrightarrow VFI$: $BCVA \propto VFI$.

Loss of visual field (*VFI*) leads to a decrease in visual acuity (*BCVA*);

5. $Age \leftrightarrow RQ, VFI$: $RQ = RQ_0 \cdot e^{-k_{age} \cdot age}$; $VFI_{age} = VFI_0 - k_{age} \cdot age$;

6. $Tr \leftrightarrow IOP$: $IOP_{corr} = IOP_{meas} + k \cdot (Tr - Tr_{norm})$;

7. $\alpha/t1 \leftrightarrow Pperf, RQ$: $RQ = RQ_{base} \cdot \alpha/t1\ (P_{perf})$;

8. $Additional\ factor \leftrightarrow IOP, RQ$: $IOP = IOP_0 + k_{add} \cdot Factor$; $RQ = RQ_0 \cdot e^{-k\_add \cdot Factor}$

The S_{eye} model is a mathematical model with nonlinear dependencies that allows for the quantitative assessment of the complex impact of various factors on the condition of the eye. The model flexibly considers the characteristics of each parameter through their transformations and weighting factors. Nonlinearities are introduced using exponential and polynomial functions, selected based on biological logic or empirical data [17, 18], which allowed the model parameters to be represented as follows:

$$IOP_{effect} log(IOP + 1);\ RQ_{effect}\ log\left(RQ_{effect} + 1\right);\ BCVA_{effect}(BCVA - h)^2; \tag{2}$$
$$Tr_{effect} = log(Tr + 1);\ VFI_{effect} = e^{-VFI};\ Pperf_{effect} = log(Pperf + 1);$$
$$\frac{\alpha}{t1_{effect}} = log\left(\frac{\alpha}{t1} + 1\right);\ age_{effect} = log(age + 1);$$
$$additional\_factor_{efftct} = e^{additional-factor},$$

where h is the threshold value for BCVA (empirically chosen).

Nonlinear dependencies in the model (logarithmic, parabolic, and exponential) account for the different effects of parameters on the state of the eye. Logarithmic dependencies (e.g., *IOP, RQ, Tr, Pperf, age*) describe increasing influence with a decelerating rate. The parabolic dependence (*BCVA*) shows an intensification of the effect up to a certain level, followed by its decrease. Exponential dependencies (*VFI, additional_factor*) reflect sharp changes in influence during fluctuations of parameters. This approach, based on theoretical and practical data, allows for accounting complex interactions of factors, making the model more accurate and realistic.

To implement the model, Python was used due to its convenient syntax, cross-platform compatibility, and the availability of powerful libraries (such as scipy.optimize and scikit-learn), which provide numerical optimization and machine learning capabilities [19]. The eye state model depends on parameters (e.g., *IOP, BCVA*) and their weight coefficients *k1, k2,...,k9*, which significantly impact the final value of Seye. Changes in parameters, such as *IOP* (by 5-10 mm Hg) or *BCVA* (from 1.0 to 0.1), can significantly vary the result from normal to pathological states (e.g., glaucoma or complete blindness).

To optimize the coefficients *k1,k2,...,k9*, the L-BFGS-B method from the SciPy library was used [19]. This iterative gradient-based method is suitable for problems with a large number of variables as it utilizes an approximate Hessian matrix, speeding up the process and improving accuracy. The method sets initial values, defines parameter bounds, and minimizes the objective function S_{eye}, efficiently optimizing the nonlinear dependencies of the model.

The optimization algorithm for *k1, k2,...,k9* using the L-BFGS-B method includes:

• Objective: Minimize the objective function by calculating the optimal coefficients *k1, k2,..., k9* to determine the state of the eye, considering nonlinear dependencies on parameters.

• Steps of the algorithm:

1. Initialization:

- Request parameter values for analyzing the eye's state (*IOP, RQ, BCVA, Tr, VFI, Pperf, alpha, age, additional_factor*).
- Set initial values for coefficients *k1, k2,...,k9* (e.g., ranging from 0.1 to 10.0).
- Input constraints on the ranges of *k1, k2, ...,k9*.

Each parameter *k1, k2, ...,k9* is bounded within a specific range:

$$ai \le ki \le bi.$$

This ensures a physical interpretation of the parameters and prevents invalid values. The method accounts for constraints through gradient projection. At each step, it checks whether the parameters *k1,* *k2*, ...,*k9* exceed the boundaries $[a_i, b_i]$. If they do, the current value of k_i is projected onto the permissible range:

$$k_i = proj_{[a_i, b_i]}(k_i) - \min(\max(k_i, a_i), b_i). \quad (3)$$

A function is defined that calculates the eye condition indicator (S_{eye}) based on the input parameter values, including the coefficients.

2. Defining the objective function:

- Describe the eye condition function (*calculate_*S_{eye}), which depends on parameters and the optimized coefficients *k1*,*k2*,...,*k9*. This function will account for nonlinear dependencies, such as: logarithmic relationships for parameters *IOP, RQ, Tr, alpha*, and *Pperf*; parabolic relationships for visual acuity (*BCVA*); exponential relationships for *VFI* and additional_factor.

- Calculate the eye condition (S_{eye}), considering all parameters.

- Define the objective function for minimization. The objective function will compute the error or deviation from the ideal eye condition value based on the current values of the coefficients *k1*,*k2*, ...,*k9*. The objective function for minimization, to compute the eye condition value based on the current coefficients *k1*,*k2*,...,*k9*, takes the following form:

$$\min_{k_1, k_2, \ldots, k_9} = \frac{1}{N}\sum_{i=1}^{N} \left(Seye_{pred}\left(k_1, k_2, \ldots, k_9, a_i\right) - Seye_{obs,i}\right)^2, \quad (4)$$

where $Seye_{pred}$ - the value calculated using the model, including nonlinear dependencies for all parameters;

$Seye_{obs}$ - reference or observed data;

a_i – model parameters.

3. Optimization using the L-BFGS-B method: Use scipy.optimize.minimize() with the L-BFGS-B method to minimize the objective function; obtain the optimized values of coefficients *k1*,*k2*,...,*k9* that minimize the deviation of the eye condition from the target value.

4. Update: At each iteration step, the following are performed: updating parameters *k1*,*k2*,...,*k9* using the Hessian approximation and projection.

5. Termination criterion: The algorithm terminates when the change in *k1*,*k2*,...,*k9* or the gradient becomes less than a given threshold.

6. Result: Calculation of the eye condition using *k1*,*k2*,...,*k9*.

7. Output of optimized coefficients and computed eye condition considering the coefficients.

8. Plotting graphs to visualize the relationship between the eye condition and various parameters.

Figure 1 shows the contour plot of the objective function for the coefficients *k1* and *k2* of the model, with the other parameters held fixed. This visualization approach helps to analyze the dependence of the error function, identify key trends, and understand the impact of the parameters on the result. The two-dimensional representation simplifies finding extrema, adjusting initial values, and improving the optimization process.

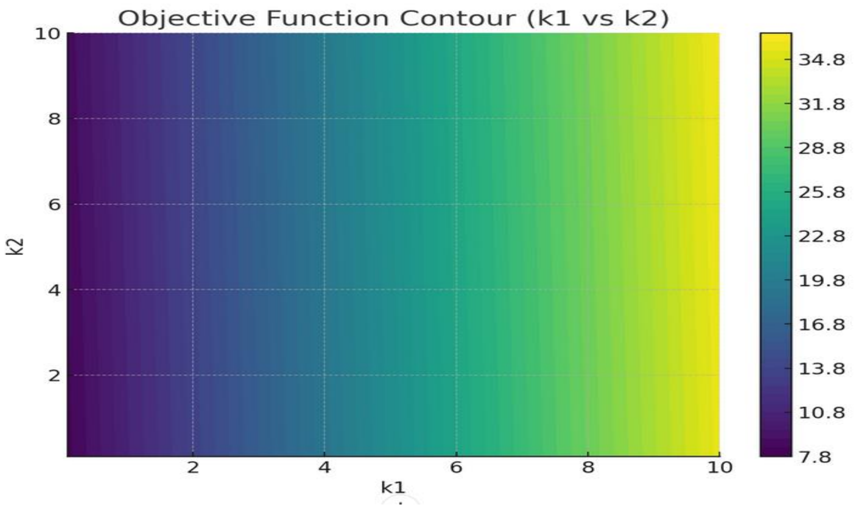

Fig. 1 – Contour plot of the objective function for the two coefficients *k1* and *k2*

The graph demonstrates the dependence of the loss function on the parameters *k1* and *k2*, which vary from 0 to 10. The color scale represents the function values: green shades correspond to the minimum (closer to the optimum), while purple represents the maximum values. The contours denote lines of equal error, helping to localize the minima and maxima. The function values range from 7.8 to 35, with the lowest errors in the central region. The use of two parameters for visualization is explained by the need to simplify the analysis in multidimensional problems. This approach allows an intuitive understanding of the dynamics of optimization and the influence of parameters on the function. For analyzing all nine parameters, more complex methods are required, such as projections or multidimensional analysis. Examples in Figures 2 and 3 show the simulation results for the state of the eye (S_{eye}) depending on the parameters *VF1* and *RQ*, taking their nonlinearity and the optimization of the model's weight coefficients into account.

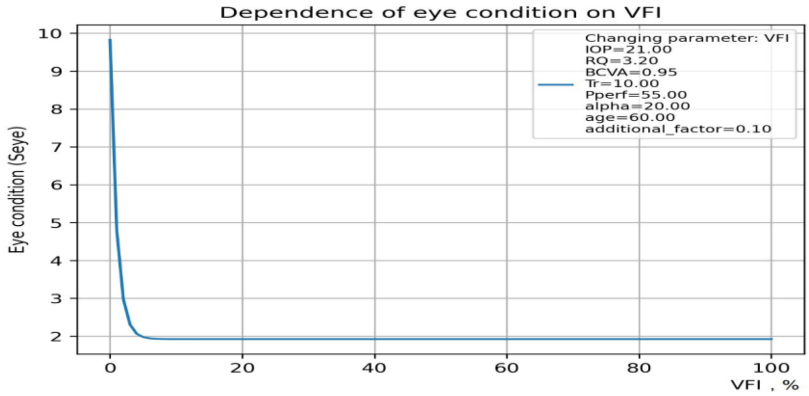

Fig. 2 – State of the eye (S_{eye}) based on changes in *VF1*

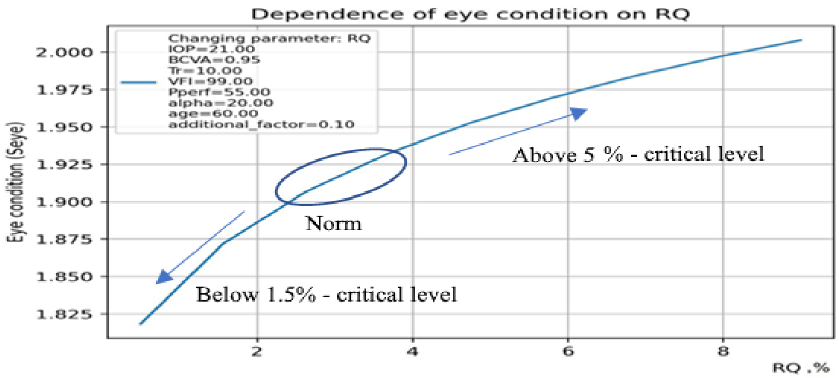

Fig. 3 – State of the eye (S_{eye}) based on changes in *RQ*

The analysis of the graph showing the change in the eye's state (S_{eye}) based on changes in *VF1* (Fig. 2) reveals an exponential decrease in S_{eye} as the *VFI* value increases. *VFI* reflects the visual field function, influenced by other factors. The relationship between S_{eye} and *VFI* is nonlinear and exhibits an asymptotic pattern. The exponential influence (*VFI* graph) highlights the high sensitivity of the eye's state to a decline in its functionality, with particularly strong effects at lower values. This suggests that during the early stages of *VFI* deterioration, the eye's state is most sensitive to changes, and any decrease in the visual field below 100% affects visual function and structural-functional damage to the optic nerve. Therefore, maintaining *VFI* at 100% is crucial for stabilizing the eye's state. High *VFI* values (close to 100%, representing near-complete preservation of functionality) have less impact on the eye's condition. A decrease in *VFI* is likely linked to the overall deterioration of the ocular structures, resulting in significant changes in S_{eye}. The graph clearly shows a sharp decline in the eye's condition (S_{eye}) when *VFI* drops below 100%. A visual field loss of more than 50% (*VFI* < 50%) may be irreversible and associated with the terminal stage of glaucoma. Some stabilization of S_{eye} at around ~2 when *VFI* is

100% suggests that maintaining this parameter helps preserve the structural-functional parameters of the visual system and keeps the eye's state stable. This graph also indicates that even with normal intraocular pressure, a decrease in *VFI* reveals all the traditional signs of disease, such as glaucomatous optic nerve damage, which is reflected in the eye's state.

The analysis of the graph showing the change in the eye's state (S_{eye}) based on changes in *RQ* (Fig. 3) demonstrates that Seye increases as *RQ* increases, indicating a negative correlation between the parameters. The increase in Seye is nearly linear across the entire range of *RQ* values (from 1% to 8%). This could be related to a decrease in ocular circulation (*RQ* up to 3.2%), which may occur with age-related changes in the eye, glaucoma, high myopia, or the manifestation of ischemic diseases affecting the head and eyes. The linear growth suggests the presence of critical thresholds or saturation points (below 1.5% and above 5%), making *RQ* an important parameter for improving the eye's state. The absence of saturation indicates a constant impact of *RQ* on the eye's condition.

An increase in *RQ* directly improves the eye's condition (S_{eye}), and the effect is consistent across the entire range of values. This highlights the importance of controlling or increasing the *RQ* parameter to maintain eye health, especially when other parameters, like *VFI*, are stable within normal ranges. Such a relationship can be used as an indicator for assessing the quality of therapy or vision correction.

The parameters *VFI* and *RQ* are key factors influencing S_{eye}, each with different characteristics:

- *VFI* has the greatest impact on the eye's state in the early stages of deterioration, related to the progression of diseases affecting the visual field.
- *RQ* reflects changes in the eye's state nonlinearly, highlighting the importance of intraocular circulation in the condition and function of the eye.

Possible diagnoses:

- Glaucoma: Low *VFI* values, particularly when combined with elevated intraocular pressure (*IOP*), and a decrease in visual acuity (*BCVA*), are markers of disease progression.
- Age-related eye diseases (e.g., age-related macular degeneration, cataracts): Low *RQ* leads to reduced perfusion pressure, diminishing blood, oxygen, and nutrient supply to the eye's structures, slowing metabolic processes and promoting the accumulation of metabolic waste. High *RQ* may indicate congestion within the eye (e.g., retinal vein occlusion, neovascular glaucoma, or intraocular inflammation), which can significantly affect overall vision health.

Recommendations:

Maintaining the most preserved visual field (*VFI*=100%) should be the primary goal of therapy, especially for patients with glaucoma.

Continuous monitoring of *RQ*, especially in elderly patients diagnosed with intraocular diseases. Improving intraocular volumetric blood circulation (through physiotherapeutic methods such as laser stimulation, electrophoresis with vascular medications, and pharmacological therapy) helps improve the eye's condition.

To maintain eye health, a comprehensive approach is required, taking into account the interaction between various model parameters. It is crucial to analyze both the individual effects of each parameter and their interrelationships. For example, high *IOP* leads to a decrease in *Pperf*, which negatively affects intraocular blood circulation (*RQ*) and contributes to the development of ischemic diseases, ultimately affecting vision. The interaction between *VFI, IOP* and *RQ* shows that vision field deterioration is closely linked to both intraocular pressure and insufficient blood supply. The *Pperf* parameter helps improve blood flow, which positively affects the general condition of the eye, but its influence is highly dependent on *RQ*. *Alpha* (α/t_1) has an indirect effect through a complex of factors, while age (*Age*) is associated with a decrease in *BCVA* and *VFI,* making it an important parameter for assessing age-related changes in visual acuity. Maintaining the *VFI* parameter at its maximum level helps stabilize the eye's condition, while a decrease in *VFI* may indicate the development or progression of glaucoma. The *Tr* parameter is closely related to *BCVA*: a reduction in tear production can cause dry eye syndrome and significantly reduce visual acuity, which reflects the eye's condition.

To validate the program's functionality and the accuracy of calculations, module tests were performed covering various scenarios of input data changes. This allowed for assessing the model's response to different conditions. Particular attention was given to the model's sensitivity, including the impact of parameters such as the shape of the eyeball or retinal light sensitivity. Sensitivity analysis revealed vulnerabilities and helped improve the algorithm's robustness. The accuracy of calculations was verified using both quantitative methods, comparing results with expected values, and qualitative

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methods, evaluating the match with theoretical expectations. To assess practical applicability, scenarios close to real medical practice were tested. This approach ensured the model's predictive accuracy and its practical value in medical and technological applications.

Example of modular testing

```
import unittest
# Modular tests for functions
class TestSeyeCalculation(unittest.TestCase):
   # Test the function for nonlinear IOP dependency
   def test_non_linear_iop(self):
      self.assertAlmostEqual(non_linear_iop(10), np.exp(10 / 10), places=5)
      self.assertAlmostEqual(non_linear_iop(0), np.exp(0 / 10), places=5)
   # Test the function for nonlinear tear quality dependency
   def test_non_linear_q(self):
      self.assertAlmostEqual(non_linear_q(50, 60), np.log(50 + 1) * np.sqrt(60), places=5)

   # Test Seye calculation with fixed values    def test_calculate_seye_with_fixed_values(self):
      iop = 20
      q = 50
      v = 90
      tr = 10
      pvf = 3
      pperf = 5
      rvessels = 2
      age = 60
      additional_factor = 2
          expected_seye = (optimized_coefficients[0] * non_linear_iop(iop) +
                 optimized_coefficients[1] * non_linear_q(q, age) +
                 optimized_coefficients[2] * non_linear_v(v, age) +
                 optimized_coefficients[3] * non_linear_tr(tr, age) +
                 optimized_coefficients[4] * non_linear_pvf(pvf) +
                 optimized_coefficients[5] * non_linear_pperf(pperf) +
                 optimized_coefficients[6] * non_linear_rvessels(rvessels) +
                 optimized_coefficients[7] * non_linear_age(age) +
                 optimized_coefficients[8] * non_linear_additional_factor(additional_factor))
          self.assertAlmostEqual(calculate_seye_with_optimized_coeffs(iop, q, v, tr, pvf, pperf,
rvessels, age, additional_factor, optimized_coefficients), expected_seye, places=5)
if __name__ == '__main__':
   unittest.main()
```

For model adequacy testing, it is compared with existing scientific and medical models. The new model demonstrates compliance with standards and improves current approaches, particularly in the aspects of parameter interactions and forecasting their impact on eye health.

Conclusions

The developed eye state model effectively considers key parameters and their complex nonlinear interactions, making it a tool for diagnosis, forecasting, and personalized treatment. The model, which has demonstrated adequate results in the context of ophthalmological practice, can be used for early diagnosis, monitoring disease progression, and developing individual treatment strategies.

The eye state model serves several key functions: early diagnosis, monitoring and forecasting diseases, as well as treatment personalization. It analyzes the main parameters of the human eye, identifying diseases at early stages and predicting their development. For example, high *IOP* with low *RQ* may indicate a risk of glaucoma, and a reduction in *VFI* against the background of increased *IOP* signals glaucoma progression. The model also considers interactions between parameters such as age, *Pperf*, *BCVA* and *RQ*, which helps predict disease risks associated with ischemia, such as age-related macular degeneration, ischemic optic neuropathy, atherosclerotic or diabetic retinopathy.

Possible applications of the model include adaptive diagnostics considering individual patient characteristics, improving the accuracy of disease forecasting, integration with artificial intelligence for automated diagnostics and model adaptation. Additionally, the model could be integrated with virtual and augmented reality, as well as with laser and pharmacological treatment methods to enhance therapy effectiveness and patient quality of life.

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РОЗРОБКА ТА ДОСЛІДЖЕННЯ ЕФЕКТИВНОСТІ ІНФОРМАЦІЙНОЇ СИСТЕМИ ПАРСИНГУ САЙТІВ ІЗ ВИКОРИСТАННЯМ ФРЕЙМВОРКУ SELENIDE

Стаття присвячена дослідженню методів автоматизації збору даних із вебсайтів за допомогою технологій парсингу. У роботі описано основні переваги парсингу порівняно з ручним збором даних, наведено класифікацію існуючих парсерів, їх можливості, обмеження та застосування в реальних проєктах. Проведено детальний аналіз популярних комерційних та безкоштовних парсерів, таких як Import.io, Webhose.io, Dexi.io, Scraperhub, ParseHub, Visual Scraper, Spinn3r, 80legs, Scraper, OutWit Hub, з метою визначення їх переваг та недоліків у різних сценаріях використання. Особливу увагу приділено порівнянню фреймворків Selenium та Selenide, що широко застосовуються для автоматизації взаємодії з веббраузерами. Зроблено висновок про доцільність використання фреймворку Selenide завдяки його спрощеному синтаксису, можливостям роботи з динамічним контентом та підтримці інтелектуального очікування. У статті представлено розробку власного парсера на базі Selenide, орієнтованого на потреби малих і середніх підприємств із обмеженим бюджетом. Система побудована на сучасному технологічному стеку, що включає Java 11, Python, PostgreSQL, Angular 12, Docker, Gradle, Kafka, Node.js. Детально описано архітектуру програми, взаємодію між модулями, а також реляційну модель бази даних для зберігання отриманих даних. Запропонований підхід дозволяє налаштовувати парсер для роботи з різними типами сайтів, забезпечує високу швидкість збору та обробки інформації, а також гнучкість у налаштуванні параметрів вибірки. Створений інструмент надає можливість використовувати технології контейнеризації для спрощення розгортання та підтримки додатка. Результати роботи можуть бути використані для реалізації ефективних інформаційно-пошукових систем та автоматизації рутинних процесів збору даних, що особливо актуально для компаній, які прагнуть оптимізувати свої бізнес-процеси та зменшити витрати.

***Ключові слова:** парсинг, парсер, сайт, вебдодаток, інформаційно-пошукова система, дані, Selenium, Selenide.*

[1] *канд. техн. наук, доцент, ДВНЗ «Приазовський державний технічний університет», м. Дніпро/Маріуполь, ORCID: 0000-0003-1328-2572, sergienko_a_v@pstu.edu*
[2] *канд. техн. наук, доцент, ДВНЗ «Приазовський державний технічний університет», м. Дніпро/Маріуполь, ORCID: 0000-0003-1461-4399, balalaeva_e_u@pstu.edu*
[3] *канд. техн. наук, доцент, НТУ «Дніпровська політехніка», м. Дніпро, ORCID: 0000-0003-1190-1501, garkusha.i.m@nmu.one*
[4] *магістр, ДВНЗ «Приазовський державний технічний університет», м. Дніпро/Маріуполь, platonov_d_m@pstu.edu*