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INFORMATION TECHNOLOGY FOR INTERACTIVE VISUALIZATION OF THE LEARNING EXPERIMENT RESULTS

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The aspects of preparing engineering degree specialists in the context of performing branch-oriented laboratory works, with acquiring competencies in interpreting experimental results, are considered. An analysis of recent research and advanced practices regarding technologies and tools for developing visualization software is conducted, demonstrating a lack of experience in implementing such solutions in educational institutions, particularly for trainees without well-stable data handling skills. The relevance and necessity of designing service modules for interactive visualization of experimental data are demonstrated and substantiated. These modules should organically complement the main environment of modeling and research the subject area, providing automation of data processing and presentation processes, and meeting modern requirements for accuracy, convenience, and integration. The separation of the initial code of experimental scheme constructor is performed and designing specialized tools for processing research results with encapsulation of a set of related functions and data using the plugin mechanism. An algorithm is developed for generating standardized reporting documentation, with support for scenarios of targeted delivery of graphical and tabular structures, as well as personalized information about the performer, to widely used office suite environments.

Keywords: *experimental research environment, virtual laboratory, plugin, transition processes, host service, interactive visualization, educational and professional program.*

Problem statement. One of the key aspects of preparing engineering degree specialists involves gaining experience in constructing learning experiment schemes and subsequently presenting the research results in a correct format according to established requirements. However, commonly used open-access environments for subject area modeling do not fully possess a sufficiently developed toolkit for creating specialized visualizations and reporting. The main issue here lies in transferring the obtained data to third-party visualization means that offer functionality for presenting results visually. Here arises the need for intermediate data export to formats compatible with graphical interpretation platforms, which will divert students' attention from the substantive part of the experiment and generally pose difficulties for trainees in introductory courses who have not yet gained confidence in working with complex software on non-standardized foreign language interfaces. Therefore, when deploying learning experiment environments, it is necessary to focus on creating integrated solutions for targeted interface interaction, which will ensure seamless transition from data gathering to visualization, minimizing the need for additional user manipulations.

Analysis of recent research and publications. The necessity to develop and refine approaches to interactive visualization of experimental data has become a pressing issue in contemporary scientific research, encompassing a review of existing technologies and development tools for integrated environments [1], their capabilities [2], limitations [3], as well as an analysis of experiences in implementing similar solutions in educational institutions aimed at streamlining these processes. Thus, the image fusion technique proposed in [4] proves suitable for rapidly visualizing complex experiment scenarios. The standardized evaluation index with approximate spatial information [5] has facilitated real-time IoT visualization using original digital models. Additionally, the visualization platform for displaying analysis results in the form of diagrams [6] effectively ensures monitoring, control, and decision support for IoT devices.

The application of instrumental visualization approaches to facilitate understanding of the mechanisms of implementing variability in OOP [7] adapts the subject area for demonstration in a unified code base. The angle to visualizing short-term situations [8] provides a versatile tool for explaining complex content to various audiences. The challenges of implementing variability in the visualization process are addressed in [9] through function models for encoding knowledge about best practices and a subsequent phased configuration and evaluation process of the proposal for a specific tool, opening new opportunities for research at the intersection of visualization data and variability.

The set of automation tools and experiment planning processes simplification [10] provides visualization for data analysis in browsers regardless of processing or pre-rendering needs. The use of dynamic visualization methods for building conceptual models in diagrammatic representations of the subject area opens up broad integration possibilities in industrial modeling [11] and in multimedia educational environments for studying structured subject area [12].

The analysis of cited and other publications indicates significant interest and demand for the development of technologies that automate data visualization processes. However, while highlighting powerful modeling and visualization means, their complexity for beginners without stable data handling skills is often overlooked. Additionally, there is incomplete exploration of avenues for simplifying these processes, reducing technical barriers for students, enabling them to focus on the analytical aspects of the experiment. Consequently, there is pressing task of finding optimal approaches and designing software modules for interactive visualization of experimental data, which would organically complement the main environment of modeling and research of the subject area, ensuring the automation of data working and presentation processes, and meet the modern requirements of accuracy, convenience and integration, satisfying the needs educational program in universality and adaptation to different types of learning experiment data and scenarios of their use.

Aim of article is to perform the separation of initial code the learning experiment environment and further integration of specialized tools for processing research results with automatic filtering and categorization of specified ranges of numerical data in form of graphs, diagrams, and tables, followed by interactive visualization. This will not only enable the presentation of results in common formats while preserving the characteristics and regularities of the investigated process but also provide flexible opportunities for detailed analytics and ordering when generating reporting documentation.

Presentation of the main research material. The information formalization obtained from the learning experiment and its subsequent transformation into widely used visualization models involves structuring and arranges the data array, enabling a reasoned selection of appropriate mathematical and statistical methods for algorithms construction for prediction, interpretation of results, and decision-making. The designed module is intended for visualization and analysis of transient processes in localized regions of rout technological map of the pre-compiled learning experiment scheme (Fig. 1).

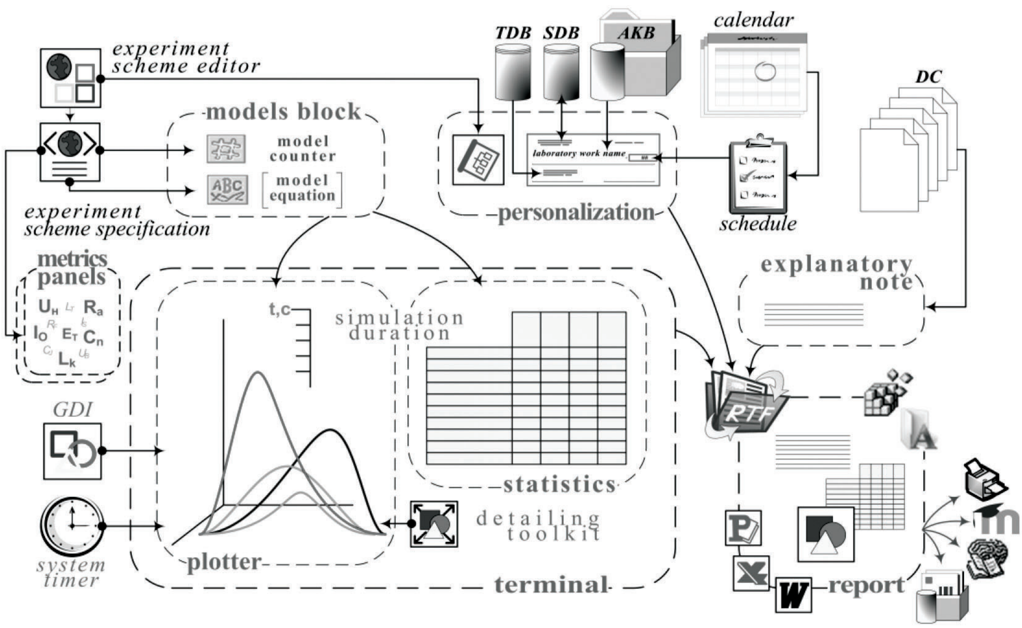


Fig. 1. Conceptual model the transient processes visualization plugin

The object-oriented environment of the *experiment scheme editor* provides an interactive toolkit for composing virtual profiled equipment, which is identical to the configuration of the physical laboratory setup. The *experiment scheme specification* hierarchically organizes the substantive parameters of bench components and structured relationships among them in the form of hyperlinks, suitable for arbitrary access and further processing. Therefore, after loading the designed *transient processes visualization plugin* and data flow processing of *REGIONS LIST* hypertag (Fig. 2), the **models block** initiates a circuits counter based on the number of trajectories (***p***) of branched technological map, previously localized by user in *experiment scheme editor*.

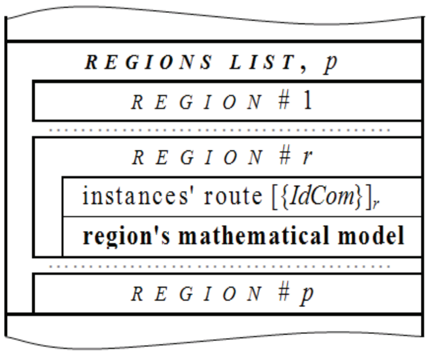


Fig. 2. Structure of *REGIONS LIST* hypertag

For each circuit (region), a system of mathematical relationships describing the current transient process is formalized based on the content of the corresponding tag. Kinetic scrolling is provided for viewing dynamically generated fields with formalized expressions (Fig. 3, *c*). The status bar, in particular, displays the total number and sequential numbers of equations (*b*) shown in **models block** limited frame (Fig. 1).

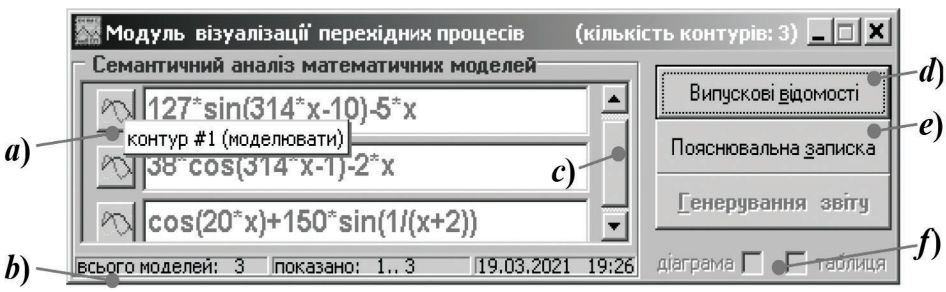


Fig. 3. Start screen of the transient process visualization plugin

To research the desired transient process, it is necessary to command button select of the mathematical model for corresponding region (*a*). This activates the equation and the chart and table controls, which constitute the terminal fields (Fig. 1) of transient processes visualization module and are initially unavailable on the start screen (Fig. 3, *f*).

When the chart control element is activated, the **plotter** terminal block (Fig. 1) opens, implemented using the free TeeChart Standard library from Steema Software for Embarcadero RAD Studio 11 Alexandria. The workspace of this block is a coordinate system (Fig. 4) with visualized transient characteristics of the processes described by the active mathematical models (Fig. 3, *a*).

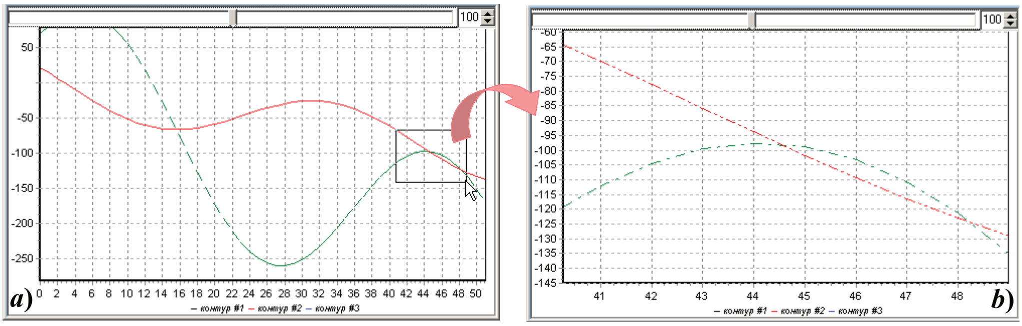


Fig. 4. Actions sequence and detailing result for fragment the transitional characteristic’

For comprehensive analysis of transient processes, the plotter block provides several control elements. For instance, by double-clicking the workspace in the upper part of the window, an interactive scale appears, allowing for smooth adjustment of the time interval over which the graphs are visualized. The maximum value of this scale can be set using a corresponding widget within a broader range, with a discrete step of ten seconds. Effective panning of the **plotter** terminal block workspace is implemented through two-dimensional canvas translation using the auxiliary key of the manipulator. Conversely, the primary key of the manipulator allows for functional detailing of a significant fragment of the transient characteristic by defining its boundaries on the canvas (Fig. 4, *a*). As result, the reference values of the coordinate plane are promptly restructured, detailing the specified fragment across the entire canvas of the workspace (Fig. 4, *b*). To restore the initial observation conditions, the graph must be fixed while holding the [Ctrl] key. Thus, the interaction tools of the **plotter** terminal block provide a sufficiently flexible toolkit for visualizing and subsequently analyzing the graphical characteristics of transient processes in the localized trajectories of the experimental scheme. As noted, any characteristic can be toggled on or off in real-time by selecting its equation in the **models block** frame. These characteristics are differentiated by color and style, as indicated in the legend.

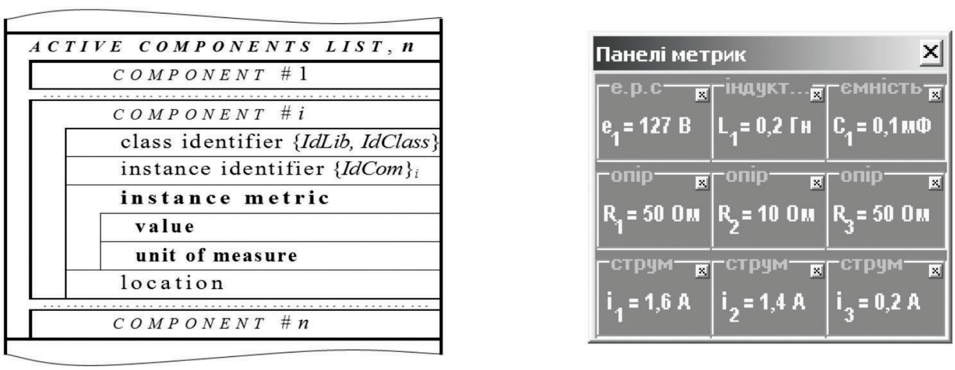
Another aspect of the computational capabilities of the transient processes visualization plugin is the binding of meaningful instantaneous parameter values of active mathematical models to specified moments in time and organizing the resulting two-dimensional array of dependencies into a table structure. When the table control element is activated (Fig. 3, *f*), the **statistics** block (Fig. 5) opens, implemented using AdvStringGrid component from the TMS Component Pack library.

t,c	K1(t)	K2(t)	K3(t)
42	-104,4433042	-77,7645379	3,0415621794
43	-99,579842190	-85,788295576	4,0323528958
44	-97,637881637	-93,817411797	4,1985865803
45	-98,793136670	-101,69927837	3,2574952749
46	-103,1429250	-109,2850141	2,2408682790

Fig. 5. Terminal block of **statistics** with instant dependencies for available regions

The table heading contains identifiers for the investigated parameters, while sidehead displays the current values of the modeling duration in seconds. Kinetic scrollbars allow browsing through the tuples of simulated dependencies with header row fixed. Terminal **statistics** block adaptively expands by visualizing a dynamically generated column for each activated equation (Fig. 3, *a*) according to the display size of the end-user's media platform in the virtual laboratory. If the screen area is limited, horizontal scrolling controls appear automatically. Similarly to the graphical characteristics, the columns of deactivated regions are also hidden. The discussed tool for adjusting the modeling duration (Fig. 4) results in a change in the number of tuples. The structured statistical data of instantaneous values are suitable for sorting, segmentation, and other analyses.

Current readings visualization of virtual equipment in composed scheme of learning experiment (Fig. 1) is carried out using the **metrics panels** block. The effective monitoring of quantitative parameters of analyzed bench is ensured by meaningful sections content from *experiment scheme specification*. So, analytical apparatus of designed transient process visualization plugin indicates the metric for $\{IdCom\}_i$ instance from ACTIVE COMPONENTS hypertag (Fig. 6, *a*) in real-time on target panel (Fig. 6, *b*).



a) b)

Fig. 6. Metrics visualization by headings of ACTIVE COMPONENTS LIST hypertag

The **metrics panels** block is accessed from system menu of main window the transient processes visualization plugin. Any panel can be disabled as needed from its control or from block's system menu. Integrating means the virtual laboratory into academic information space are concentrated in the **personalization** block (Fig. 1).

After successful authorization in the Student Database (*SDB*), the performer of the laboratory work retrieves methodological materials from the Academic Knowledge Base (*AKB*), indexed according to the *schedule* of classes valid for the current *calendar* date. These data constitute [output information] of laboratory work being performed (Fig. 3, *d*) and are automatically populated in **personalization** form. The *experiment scheme* is also displayed, with its bitmap received from the *editor* in the same data package (Fig. 1). If the scheme image is too large for available frame, it can be viewed in parts. Relevant information from laboratory work, provided by the discipline curriculum (*DC*), is shown in **explanatory note** block. To cumulating prevent of cumbersome toolkit that significantly limit the workspace, controls from application window of explanatory note are also located in system menu.

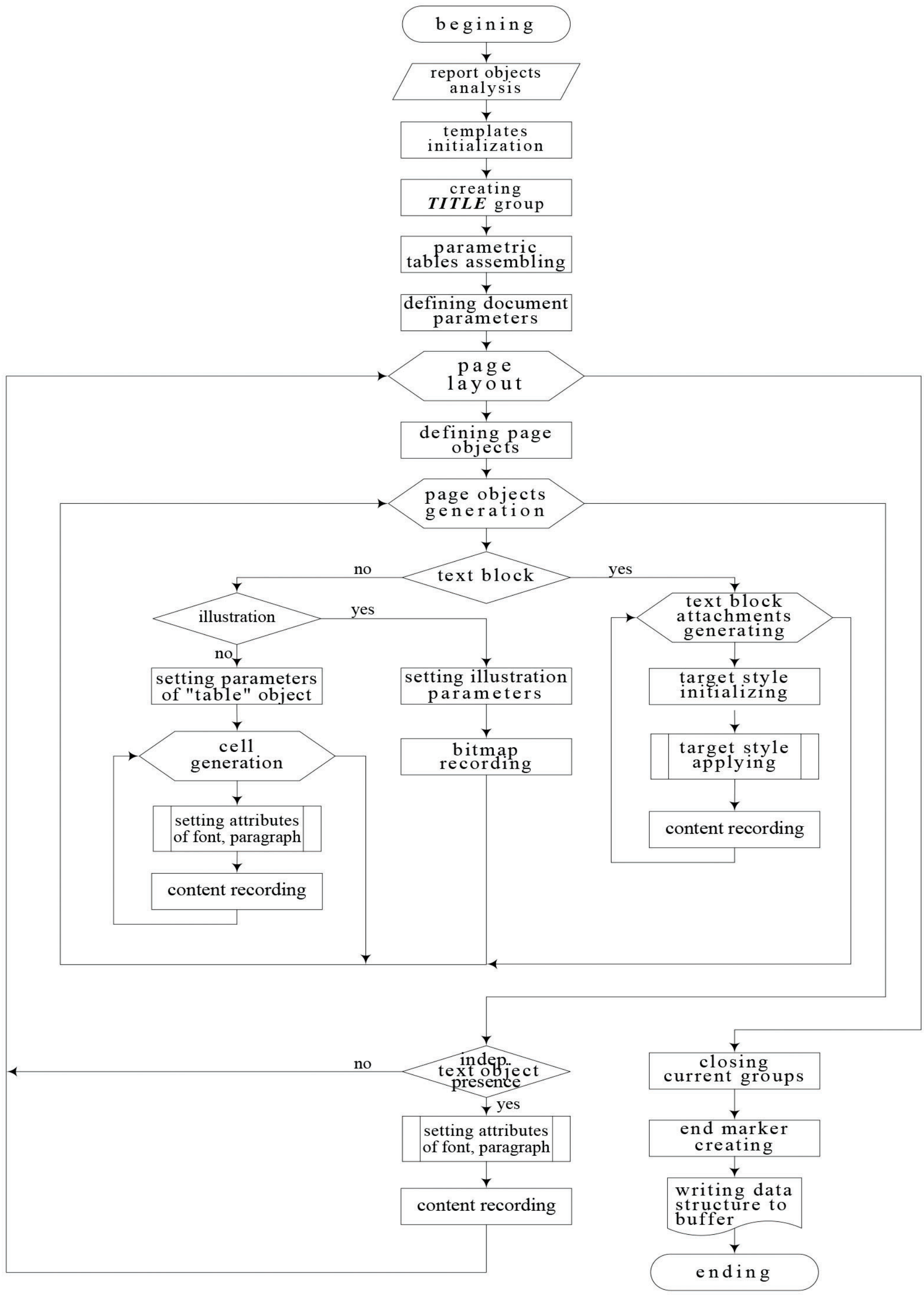


Fig. 7. Algorithm for generating the report documentation

To document the completed laboratory tasks in the designed visualizing transient processes plugin, a converter has been developed to transform the obtained research results of learning experiment scheme into commonly accepted office formats. This converter is activated by [report generation] command button, which becomes available when at least one model is activated (Fig. 3, *a*). The **report** block operates based on original algorithm for generating the advanced **.RTF* file (Fig. 7), composed of graphical, textual, and tabular structures (Fig. 1) according to established requirements for preparation of written works. Generated report documentation file (Fig. 7) is suitable for refinement and supplementation by office suite editors (Fig. 8), further printing, storage in academic repository or departmental archive, and distribution via existing learning management systems.

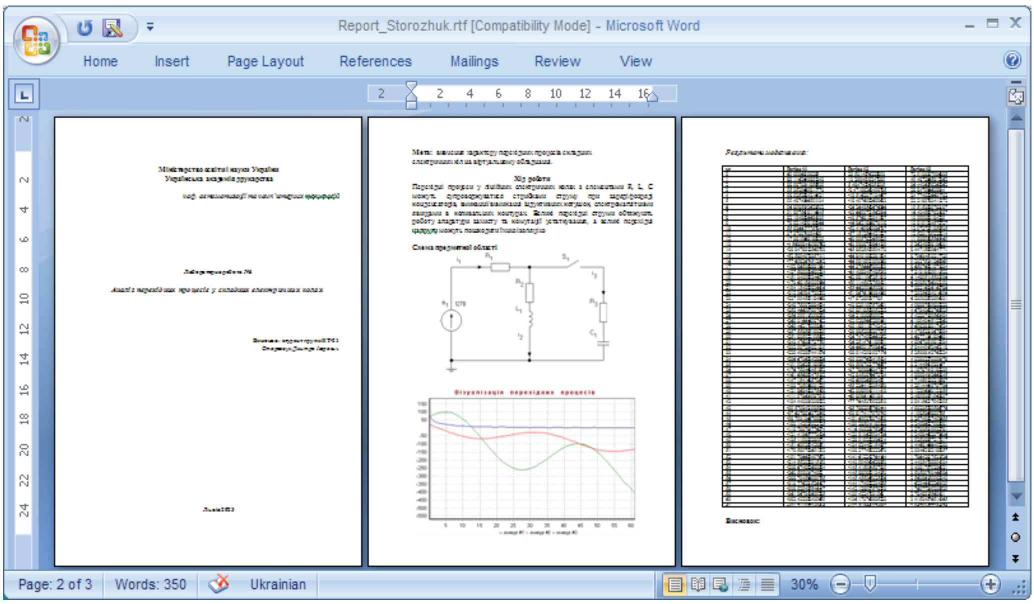


Fig. 8. Automatic delivery of reporting documentation to the office suite environment

As previously stated, the presented software module for interactive visualization of learning experiment results is implemented as a plugin, allowing for the addition or removal of functionality as per the requirements of the educational program. The plugin components and host blocks of the virtual laboratory's network environment communicate through refined interface interaction [13].

Conclusions. Therefore, the designed information technology for interactive visualization of the learning experiment results has proven to be an effective tool within the virtual laboratory environment, providing comprehensive interaction capabilities and facilitating additional data analysis. Adequate mathematical models, which accurately reflect the characteristics and patterns of the investigated transient processes, are derived from the domain specification and undergo semantic analysis. Further representation of categorized ranges of numerical data is realized through graphs, diagrams, and tables within adaptive terminal fields of the plotter and statistics with dynamic widgets of filtering, scaling, and panning.

The developed algorithm for automatic generation of standardized reporting documentation, in accordance with established formatting requirements for written works, supports scenarios for targeted delivery of graphical and tabular structures. It logs completed laboratory exercises and converts refined experiment results into common accepted office formats, including personalized details about the performer and prepared explanatory note. The presented conceptual model of the transient processes visualization plugin focuses students' attention on the substantive part of the experiment, facilitating deeper understanding, analysis, and interpretation of the obtained results, thus enhancing the quality of scientific research and its impact on the enlargement of future engineers' professional skills.

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ІНФОРМАЦІЙНА ТЕХНОЛОГІЯ ІНТЕРАКТИВНОЇ ВІЗУАЛІЗАЦІЇ РЕЗУЛЬТАТІВ НАВЧАЛЬНОГО ЕКСПЕРИМЕНТУ

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Розглянуто аспекти підготовки фахівців інженерних спеціальностей у контексті виконання галузево-орієнтованих лабораторних робіт з набуттям компетентностей інтерпретації результатів експерименту. Наголошено на важливості використання в освітньому процесі інтегрованих середовищ з адекватним функціоналом візуалізації та звітності. Виконано аналіз останніх досліджень та передових практик щодо технологій та інструментів розробки програмних засобів візуалізації, який продемонстрував відсутність досвіду впровадження подібних рішень в освітніх установах, зокрема для слухачів без стійких навичок роботи з даними. Показано актуальність та обґрунтовано необхідність проєктування сервісних модулів інтерактивної візуалізації експериментальних даних, які б органічно доповнювали основне середовище моделювання і дослідження предметної області, забезпечуючи автоматизацію процесів обробки та представлення даних, і відповідали сучасним вимогам точності, зручності, інтеграції, задовольняючи потреби освітньо-професійної програми в універсальності та адаптації до різних типів даних навчального експерименту і сценаріїв їх використання. Виконано відокремлення початкового коду конструктора схеми експерименту та долучення спеціалізованих інструментів опрацювання результатів досліджень з інкапсуляцією набору пов'язаних функцій і даних, використовуючи механізм плагіна. В середовище віртуальної лабораторії введено компонентний інтерфейс, який виконує парсер потоку даних з відповідного хост-сервіса для вилучення математичних моделей досліджуваних процесів. Компонент вхідних даних здійснює семантичний аналіз моделей та передає одержані параметри у компонент візуалізації, функціонал якого оптимізований саме для вимог конкретного навчального експерименту *чи дослідження при ефективному представленні результатів з автоматичною фільтрацією та категоризацію вказаних діапазонів числових даних у вигляді графіків, діаграм і таблиць у відповідних термінальних областях плоттера та статистики. Побудовано алгоритм генерування стандартизованої звітної документації з підтримкою сценаріїв цільової доставки графічних і табличних структур, а також персоналізованих відомостей про виконавця у середовища поширених офісних пакетів.*

Ключові слова: *середовище експериментальних досліджень, плагін, хост-сервіс, перехідні процеси, інтерактивна візуалізація, освітньо-професійна програма.*

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