



COMPUTER GRAPHICS IN THE NATURAL SCIENCES

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ABSTRACT

This article discusses the use of computer graphics in the natural sciences, its importance for visualization and analysis of complex data. Computer graphics plays an important role in such fields as physics, chemistry, biology, ecology and climatology, where it helps to model and visualize processes that are difficult to study using traditional methods. The article discusses the main types of computer graphics, such as 2D visualization, 3D modeling and simulation, as well as their application in various natural science disciplines. Particular attention is paid to modern software tools such as MATLAB, PyMOL, VMD and Blender, which are actively used for data analysis and visualization. The prospects for the development of computer graphics in the natural sciences are considered, including integration with artificial intelligence and the use of virtual reality technologies for scientific research.

INTRODUCTION

Computer graphics play a vital role in the development of modern natural sciences, providing powerful tools for visualization, analysis, and modeling of complex natural processes. In areas such as physics, chemistry, biology, ecology, and climatology, graphics technologies make it possible to visualize data that cannot be observed directly, as well as to model phenomena that are difficult to reproduce in laboratory conditions.

Progress in computer graphics has opened up new horizons for scientific research, allowing scientists to better understand complex relationships in nature, more effectively analyze experimental results, and predict the behavior of systems under various conditions. Modeling biological processes, chemical reactions, or climate change is possible thanks to modern graphics technologies, which allow not only to visualize results, but also to conduct simulations based on real data[1].

Modern computer graphics tools such as MATLAB, PyMOL, Blender, and other specialized programs enable researchers to create accurate and detailed models, conduct simulations, and analyze the results in a convenient visual form. This helps accelerate scientific progress and expands the possibilities for conducting research in areas where traditional methods are limited[2].



The purpose of this article is to analyze the use of computer graphics in the natural sciences, consider its impact on scientific research, and assess the prospects for the development of graphic technologies in this area.

RESULTS and DISCUSSIONS

The history of computer graphics in the natural sciences dates back to the mid-20th century, when the first computers began to be used for mathematical modeling and data analysis. Computer graphics demonstrated its potential for solving scientific problems, providing new tools for analyzing experimental results and predicting various phenomena. The emergence of the first programs for automated drawing and modeling made it possible to use computers to visualize complex objects and processes. These systems began to be used in physics, chemistry, and biology to create models of molecules, display chemical reactions, and visualize physical processes. During this period, computer graphics became an important tool for data analysis and the development of new research methods.

With the development of three-dimensional modeling and simulation, scientists were able to visualize complex systems more accurately and in greater detail. In physics, this led to the creation of models of quantum systems and molecular dynamics, and in biology and chemistry - to detailed models of molecules and proteins. Programs such as PyMOL for visualizing biomolecules and MATLAB for scientific calculations and data visualization have become the standard in scientific research[3].

With the development of graphics processing units (GPUs) and increased computing power, specialized simulation and visualization software products have emerged, such as VMD for molecular visualization and Blender for 3D modeling. These tools have given scientists the ability to run more complex simulations in real time, significantly accelerating research processes and increasing the accuracy of scientific data.[4]

Computer graphics continue to advance rapidly thanks to technologies such as virtual reality (VR) and augmented reality (AR). These innovations allow scientists to immerse themselves in virtual models of systems, which is especially useful for analyzing complex processes in biology, physics, and climatology. The synergy of computer graphics with artificial intelligence (AI) has also become an important step forward, allowing the automation of processing large amounts of data and creating more accurate forecasts.

The development of computer graphics has significantly influenced progress in the natural sciences, providing scientists with powerful tools for visualizing and analyzing data. Modern graphics technologies continue to advance, opening up new opportunities for scientific research and further deepening our knowledge of nature.[6] In the natural sciences, computer graphics are used to visualize complex phenomena, create models of objects, and simulate processes that cannot be directly observed or studied using traditional methods. The main types of computer graphics used in this field include 2D visualization, 3D modeling and animation, and simulations, each of which plays an important role in scientific research[7].

2D visualization is the main method of graphical representation of data in the form of graphs, charts, maps, and spectra. This type of computer graphics is widely used in the natural sciences to present experimental data, analyze dependencies, and infer patterns. For example, in physics, graphs are often used to display measurement results, in chemistry to plot the spectra of chemical substances, and in biology to present genetic maps and growth charts.



One of the key tools for 2D visualization is MATLAB, which allows you to not only build graphs and charts, but also perform mathematical processing of data. With the help of such visualizations, scientists can quickly evaluate the results of experiments, identify anomalies or confirm hypotheses.[12]

3D modeling allows you to visualize objects and processes in three-dimensional space, which is especially important for complex systems in the natural sciences. In biology, these can be models of cells, tissues or molecular structures, in chemistry - molecules and their interactions, and in physics - complex processes, such as the distribution of magnetic fields or the movement of particles in complex environments.

Programs such as PyMOL, VMD and Blender provide scientists with tools for creating detailed 3D models that help better understand the structure and behavior of systems. For example, in biology, 3D modeling can be used to study the spatial structure of proteins and their interactions with other molecules, which is key to drug development.

Animation and simulation are types of computer graphics that allow you to model and visualize dynamic processes over time. In the natural sciences, this is used to study the dynamics of systems, changes in state and behavior of various objects under the influence of external factors. For example, in physics it is possible to model the movement of particles in environments with different properties, and in biology it is possible to reproduce the life cycles of cells or evolutionary processes[9].

Simulations are used to conduct virtual experiments when reproducing real conditions is practically impossible or too expensive. This can be a simulation of chemical reactions, the interaction of ecosystems, or modeling global climate change. Thanks to graphical simulations, scientists can conduct experiments in a virtual environment and predict the results with high accuracy.

GIS is a specialized program used to visualize and analyze spatial data, which is especially useful in ecology, geology, and climatology. With the help of GIS, scientists can create maps that display ecological systems, natural resources, climate zones, and other important aspects of the environment. This type of graphics allows you to analyze spatial data, track changes, and make predictions about the state of ecosystems.

Software tools such as ArcGIS provide the ability to overlay various data layers on maps, analyze changes in ecosystems, and model scenarios for their development under the influence of various factors, such as climate change or anthropogenic impact.

Computer graphics have become an integral part of scientific research in the natural sciences. It is used to model complex processes, visualize data, simulate, and analyze experimental results. Let's consider the key areas of application of computer graphics in the natural sciences.

In physics, computer graphics are used to model and visualize complex physical processes and phenomena that cannot be observed directly. This includes simulating the behavior of particles in accelerators, modeling quantum systems, and visualizing electromagnetic fields and flows. Modern programs allow scientists to build graphical models of the interaction of elements in atomic and molecular structures, and conduct numerical simulations to study the dynamics of bodies in various environments.



One striking example is the use of computer graphics to model astrophysical phenomena. Researchers can visualize the dynamics of black holes, star systems, or galaxies, which helps to better understand the processes occurring in the Universe. These simulations allow us to observe the evolution of space objects over billions of years in a compressed time frame.

In chemistry, computer graphics is actively used to visualize molecular structures and chemical reactions. Programs such as PyMOL and VMD allow scientists to create three-dimensional models of molecules, study their spatial structure, and model their interactions. This is especially important for studying complex organic molecules such as proteins, DNA, and drugs.

Graphical simulations help chemists analyze the mechanisms of chemical reactions, predict their outcomes, and study the interactions between molecules. This opens up new possibilities for the development of drugs and materials, since scientists can model reactions at the molecular level and evaluate the effectiveness of certain compounds before conducting real experiments.

In the biological sciences, computer graphics are used to visualize and model biological systems and processes. Three-dimensional modeling of cells, tissues, organs, and organisms allows scientists to study complex biological structures and their functioning. 3D modeling programs help to study the structure of proteins, interactions between molecules, and processes occurring at the cellular level.[10]

Simulations of biological processes such as cell division, tissue growth, or evolutionary changes help biologists better understand the mechanisms underlying life. Computer graphics are also actively used in genetics to analyze genome data, visualize the evolutionary relationships between species, and model genetic changes. Computer graphics play an important role in ecology and climatology, where they are used to model natural processes and ecological systems. In ecology, graphical models help visualize changes in ecosystems under the influence of external factors, such as climate change, anthropogenic influence, and natural disasters.

In climatology, computer graphics are used to model global climate change and predict its impacts. Climate change models based on computer simulations help evaluate possible scenarios for global warming, ice cap melting, and sea level changes. Such models are used to develop strategies for adapting to climate change and mitigating its impacts.

In geology, computer graphics are used to create 3D models of the earth's crust, analyze tectonic movements, study the structure of mineral deposits, and simulate geological processes. With their help, geologists can visualize the layers of the earth, create detailed maps, and predict geodynamic changes such as crustal shifts and volcanic eruptions.

Simulations of geological processes help researchers model the evolution of the earth's crust over millions of years, which helps to better understand the history of the Earth and its development. In the field of mining, graphical models help identify the most promising areas for drilling and develop strategies for the efficient use of natural resources.

Modern advances in computer graphics and data visualization have become possible thanks to the development of powerful software tools that are widely used in the natural sciences. These tools allow scientists to create complex 2D and 3D models, simulate natural processes, visualize data, and analyze experimental results. Let's consider the main software



tools that are used to solve computer graphics problems in the natural sciences. MATLAB is one of the most common tools for mathematical modeling, data visualization, and simulations in the natural sciences. The program provides a wide range of functions for working with data and plotting graphs, which allows researchers to create both 2D and 3D visualizations. MATLAB is used in such fields as physics, biology, chemistry, and engineering to analyze experimental data, build models, and perform numerical calculations. PyMOL is a specialized tool for 3D visualization of biomolecules, which is widely used in chemistry, biology, and biochemistry. PyMOL enables the creation of accurate 3D models of molecules, proteins, and other biomolecular structures, helping scientists to study their spatial configuration and interactions with other molecules. The program supports both static visualizations and animations of molecular motion, making it an indispensable tool for research in the field of molecular biology and structural biochemistry.

Blender is a universal software tool for creating 3D models and animations, which also finds application in the natural sciences. Although Blender was originally developed for animation and graphic design, its capabilities allow you to create high-quality scientific visualizations. The program supports the construction of complex 3D models, simulation of physical processes and image rendering, which makes it useful in various fields of science, from physics to biology.

VMD is a software tool for visualizing molecular dynamics, which is used in biochemistry, molecular biology and materials science. VMD allows you to visualize the trajectories of molecules over time, analyze their behavior and simulate interactions at the molecular level. The program supports working with large data sets, which makes it useful for analyzing complex molecular systems and processes.

ArcGIS is a geographic information system (GIS) that is widely used in ecology, climatology, and geology to visualize and analyze spatial data. With ArcGIS, scientists can create detailed maps, visualize environmental and climate changes, and model the behavior of natural systems under the influence of various factors.

ParaView is a powerful tool for visualizing big scientific data that is used to process the results of numerical modeling in such fields as physics, geology, and engineering. The program supports working with large volumes of data and allows you to create three-dimensional visualizations of simulation results, such as pressure, temperature, or fluid flow distribution. ParaView is often used to analyze data obtained from modeling complex physical processes, such as turbulence, wave propagation, and fluid dynamics. This makes the program especially useful for research in the fields of hydrodynamics, thermodynamics, and materials science.

Modern development of natural sciences increasingly depends on the synergy between computer graphics and artificial intelligence (AI). This integration allows for new ways of analyzing data, modeling complex natural processes, and visualizing results, which significantly expands the possibilities of scientific research. The interaction of AI with computer graphics allows for the automation of the process of creating and analyzing visualizations, improving their accuracy, and increasing productivity in solving complex problems.

One of the key areas of AI application in natural sciences is automatic data processing and visualization. Huge amounts of data generated during experiments and observations require effective tools for their analysis and interpretation. Artificial intelligence, especially machine



learning methods and neural networks, helps automate the process of processing this data and identifying hidden patterns that can be visualized using computer graphics.

Artificial intelligence also plays an important role in improving the quality of graphical models and simulations. With the help of AI, it is possible to increase the detail of 3D models, improve the realism of simulations, and speed up the rendering process. Machine learning algorithms can optimize graphical calculations, making simulations faster and more accurate[13].

Computer graphics combined with artificial intelligence can not only visualize existing data, but also model the future behavior of complex systems. This is especially important in areas such as ecology and climatology, where it is necessary to predict the impact of various factors on natural processes. Artificial intelligence is able to learn on large data sets and build models that predict the behavior of a system depending on changing parameters.

AI significantly improves the capabilities of image processing and data visualization in the natural sciences. Deep learning and pattern recognition technologies help to automatically analyze images obtained during scientific research and build models based on them. This is used in various scientific disciplines, such as medicine, biology, geology, and astronomy.

For example, in medicine, AI is used to analyze medical images (e.g., CT and MRI), which allows for the automatic detection of pathological changes and the construction of visualizations based on this data. In astronomy, AI helps analyze deep space images by automatically identifying stars, galaxies, and other space objects, which significantly speeds up data processing and improves the quality of scientific findings.

Artificial intelligence combined with computer graphics is actively used to create interactive educational systems that help students and researchers better absorb knowledge. Virtual labs, simulators, and learning platforms supported by AI allow for virtual experiments in various fields of natural sciences, from physics to biology.

Such systems can adapt to the user's level of knowledge, providing personalized tasks and visualizations. Artificial intelligence helps analyze student actions and offer recommendations for improving their results, while graphic technologies make learning more interactive and visual.

Computer graphics continues to develop rapidly, and its impact on natural sciences is only increasing every year. New technologies allow scientists and researchers to obtain increasingly accurate and detailed visualizations, conduct complex simulations, and analyze large amounts of data. Let's consider the key trends and prospects that will determine the future of computer graphics in the natural sciences. One of the main trends is the integration of computer graphics with artificial intelligence (AI) and machine learning (ML) technologies. AI helps automate the process of data analysis and visualization, which significantly accelerates scientific research. Machine learning technologies can be used to analyze large data sets, predict system behavior, and improve the accuracy of simulations. Virtual reality (VR) and augmented reality (AR) technologies are increasingly used in the natural sciences. These technologies allow scientists and researchers to immerse themselves in virtual models of systems, interact with them in real time, and conduct experiments in conditions close to real ones. This opens up new opportunities for learning, data visualization, and analysis of processes that are difficult to reproduce in real life [7,8].



In biology and medicine, virtual reality is used to study three-dimensional models of cells and organs, and in geology, to model complex terrestrial structures. Virtual laboratories and simulations allow for virtual experiments, which is especially important for complex and expensive scientific research. Augmented reality, in turn, allows for the visualization of scientific data directly in the real world, which simplifies their analysis and demonstration.

Cloud technologies and distributed computing are becoming an important tool for the natural sciences, especially in cases where large amounts of data need to be processed or complex simulations need to be performed. Cloud platforms provide researchers with access to powerful computing resources, which allows for complex calculations and modeling to be performed in the shortest possible time.

Every year, the capabilities of computer graphics for creating realistic and detailed simulations are increasing. This is due to the development of graphics processing units (GPUs) and rendering technologies, which allow complex systems to be modeled with high accuracy. In fields such as physics, climate science, and biology, realistic simulations allow scientists to observe processes in minute detail, which significantly improves their understanding of the nature of phenomena.

Another important trend is the automation of scientific processes using computer graphics. Automated modeling and visualization technologies allow scientists to reduce the time spent on experiments and data analysis. Graphic systems can automatically process data, build models, and visualize results, which frees researchers from routine work and allows them to focus on key scientific tasks.

Artificial intelligence (AI) is playing an increasingly important role in creating and improving graphical visualizations in the natural sciences. AI can automatically generate visualizations based on large amounts of data, improving the quality of models and speeding up the rendering process. The use of neural networks in visualization allows you to create more accurate images that can be used for detailed analysis.

CONCLUSIONS

Computer graphics in the natural sciences cover a wide range of tools and methods, from simple 2D visualization to complex 3D modeling and simulation. Each type of graphics plays a unique role in data analysis, process modeling, and presentation of research results. Using these tools helps scientists better understand natural phenomena, make accurate predictions, and develop new scientific methods.

Computer graphics has become an important tool for many natural sciences, opening up new horizons for the study and analysis of complex processes and systems. Data visualization, modeling of phenomena, and simulations help scientists better understand nature, predict the behavior of systems, and develop new scientific approaches. In each discipline, be it physics, chemistry, biology, or ecology, computer graphics significantly expands the possibilities of research, making it more accurate and efficient.

Modern computer graphics software such as MATLAB, PyMOL, Blender, VMD, ArcGIS, and ParaView play a vital role in the natural sciences. They allow you to visualize complex systems, model processes, and analyze large amounts of data. These tools provide researchers with powerful capabilities for conducting experiments and analyzing results, which significantly accelerate scientific discoveries and improve the quality of research. Computer graphics



continues to evolve, and software tools are becoming more integrated and versatile, opening up new horizons for scientific research.

The integration of artificial intelligence with computer graphics in the natural sciences significantly expands the possibilities for visualization, modeling, and data analysis. AI automates complex image processing processes, improves the quality of visualizations, accelerates simulations, and helps predict the future behavior of systems. This synergy opens up new horizons for scientific research, making it more efficient and accurate. In the future, we can expect even closer integration of AI and graphics technologies, which will contribute to the further development of the natural sciences.

Trends in the development of computer graphics in the natural sciences are aimed at improving the accuracy of simulations, increasing the realism of models, and automating scientific processes. Integration with artificial intelligence, the development of cloud technologies, and the use of virtual and augmented reality open up new horizons for scientists in research and data analysis. Prospects for further development of these technologies suggest an even greater fusion of graphic solutions with AI and expanded opportunities for creating innovative scientific tools.

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