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APPLICATION OF COMPUTER MODELING IN THE STUDY OF MECHANICS

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The article investigates the issue of enhancing the effectiveness of mechanics education within engineering programs. Traditional methods, relying on lectures, paper-based problems, and limited laboratory work, often fail to provide a deep understanding of the subject due to the abstract nature of concepts, the complexity of models, and the lack of visualization and practical application. The authors argue for the necessity of integrating computer modeling, which serves as a powerful tool to overcome the limitations of traditional teaching. Computer modeling simplifies the visualization of complex mechanical processes, enables the conduction of virtual experiments, and allows for the analysis of how various parameters affect the behavior of systems. Various software tools for modeling in mechanics and their capabilities are examined. Particular attention is paid to the impact of modeling on the quality of education, including improved comprehension, skill development, and increased motivation. In conclusion, the importance of incorporating computer modeling into mechanics education is emphasized to prepare qualified engineers capable of solving complex problems in the context of modern technological development.

Keywords: *computer modeling, mechanics, engineering education, learning, visualization, dynamics, kinematics, finite element method, software, virtual experiments, clarity, interactivity, practical skills, learning effectiveness, engineering problems.*

ПРИМЕНЕНИЕ КОМПЬЮТЕРНОГО МОДЕЛИРОВАНИЯ В ИЗУЧЕНИИ МЕХАНИКИ

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В статье исследуется вопрос повышения эффективности преподавания механики в инженерных программах. Традиционные методы, основанные на лекциях, бумажных задачах и ограниченных лабораторных работах, часто не обеспечивают глубокое понимание предмета из-за абстрактности понятий, сложности моделей и недостатка визуализации и практического применения. Авторы аргументируют необходимость интеграции компьютерного моделирования, которое служит мощным инструментом для преодоления ограничений традиционного обучения. Компьютерное моделирование упрощает визуализацию сложных механических процессов, позволяет проводить виртуальные эксперименты и анализировать влияние параметров на поведение систем. Рассматриваются различные программные средства для моделирования в механике и их возможности. Особое внимание уделяется влиянию моделирования на качество образования: улучшение понимания, развитие навыков и повышение мотивации. В заключение подчеркивается важность включения компьютерного моделирования в обучение механике для подготовки квалифицированных инженеров, способных решать сложные задачи в условиях современного технологического развития.

Ключевые слова: *компьютерное моделирование, механика, инженерное образование, обучение, визуализация, динамика, кинематика, метод конечных элементов, программное обеспечение, виртуальные эксперименты, наглядность, интерактивность, практические навыки, эффективность обучения, инженерные задачи.*

Introduction

Mechanics, as a fundamental scientific discipline, plays a pivotal role in the advancement of civilization and the formation of the modern technological landscape. It serves as the foundation for understanding the physical laws governing motion and interaction of bodies, underpinning numerous engineering fields. From the design of bridges and buildings to the development of spacecraft, mechanics permeates all aspects of our lives, defining the capabilities and limitations of technological progress. In engineering education, mechanics occupies a unique position, shaping the professional competence of future engineers and providing a theoretical framework for understanding the principles of technical systems, fostering analytical skills, modeling, and the resolution of complex problems. A profound understanding of mechanics is indispensable for the successful design, calculation, and operation of technical devices and structures (e.g., automotive engineers utilize dynamics laws to calculate braking systems and stability; while constructing skyscrapers, statics and mechanics of deformable bodies are applied to ensure structural integrity).

Despite its significance and role in engineering education, traditional teaching methods face challenges hindering the development of deep comprehension, leading to reduced learning efficiency, formal assimilation of material, and insufficient graduate preparation. One critical issue is the limitation of traditional methods, which often reduce to lectures, problem-solving on paper, and laboratory works with frequently outdated equipment. Lectures represent a unidirectional transfer of information, not always facilitating active student engagement. Problem-solving on paper also has constraints, as tasks are simplified models that do not always elucidate how these models function in real-world scenarios. Furthermore, solving problems demands substantial effort in mathematical computations, potentially diverting attention from the physical essence of the problem. The lack of visual representation leads students to formally absorb material—memorizing formulas without understanding their practical applications. Consequently, students struggle to apply their knowledge to real engineering challenges. Traditional laboratory works, although offering practical experience, often fail to simulate complex processes, are time-constrained, and do not permit independent parameter exploration by students.

These issues collectively underscore the inadequacy of traditional methods in adequately preparing graduates for real-world engineering tasks. Graduates frequently lack experience in analyzing and modeling complex mechanical systems. In conclusion, the problem of traditional teaching methods in mechanics lies in their limitations, absence of visualization and animation, difficulties in understanding complex dynamic processes, lack of student engagement, constraints of laboratory work, and ultimately, insufficient graduate preparation. These challenges necessitate the pursuit of novel, more effective methods to overcome these barriers and achieve deeper understanding. Computer modeling is one such method.

Computer modeling is a powerful tool that transcends the limitations of traditional methods, visualizes abstract concepts, and creates interactive models, thereby promoting deeper comprehension and skill development in analysis. For instance, via computer modeling, one can visualize a projectile's trajectory by varying the launch angle, analyze the influence of initial velocity on flight distance [1], and more. Computer modeling enables the simulation of real engineering tasks difficult to replicate in laboratories; software can model mechanism dynamics [2], structural deformations, and aerodynamics of flying vehicles.

The integration of computer modeling into the educational process is a critical task requiring attention from instructors, methodologists, and educational program developers, and has the potential to significantly enhance teaching quality, making the study of mechanics more engaging.

Methods

Overview of Key Computer Modeling Methods as a Pedagogical Tool for Teaching Mechanics

Computer modeling represents a methodological approach to studying and analyzing complex systems and processes through the creation of digital representations, termed models, followed by computational experiments with these models. In the context of mechanics, computer modeling acts as a robust tool for investigating mechanical systems, predicting their characteristics, and optimizing parameters without resorting to costly and labor-intensive physical experiments. This approach facilitates the study of phenomena that are difficult or impossible to examine traditionally, such as the dynamics of complex mechanisms, deformations of structures under extreme loads, or fluid/gas flows in complex geometries.

At the core of computer modeling is the formulation of a mathematical model that accurately describes the behavior of the system under investigation and can be represented as a set of equations, algorithms, or rules defining the interrelations between system parameters. After developing the mathematical model, it is translated into a computer program enabling computational experiments and presenting results in numerical data, graphs, animations, or other forms. Depending on the representation and solution method of the mathematical model, computer modeling in mechanics can be classified into several primary categories: numerical modeling, analytical modeling, and the visualization and animation of mechanical processes.

Numerical modeling involves solving mathematical models by discretizing continuous equations and subsequently solving them using numerical methods. In mechanics, numerical modeling is extensively applied for analyzing complex systems where analytical solutions are absent. The core idea is to replace the continuous domain with a discrete grid composed of finite elements. Subsequently, the equations describing the system's behavior are approximated on this grid, and the resulting algebraic system is solved using numerical algorithms.

The two most widely employed numerical methods in mechanics are the Finite Element Method (FEM) [3] and the Finite Difference Method (FDM) [6]. FEM is a versatile and universal method widely used for analyzing the stress-strain state of solids, mechanical system dynamics, heat transfer, hydrodynamics, and other domains. In FEM, the studied domain is divided into a finite number of elements of varied shapes and sizes; equations governing system behavior are approximated on each element. Solutions from individual elements are aggregated to yield a solution for the entire domain. FEM allows modeling complex geometries [4], heterogeneous materials, and diverse load types. FEM is extensively applied in engineering practice for structural strength and stability analysis, parameter optimization, and behavior prediction under various operational conditions. Examples include stress analysis in bridge cranes [5] (fig. 1), wing deformation under aerodynamic forces, and thermal regime of electronic components.

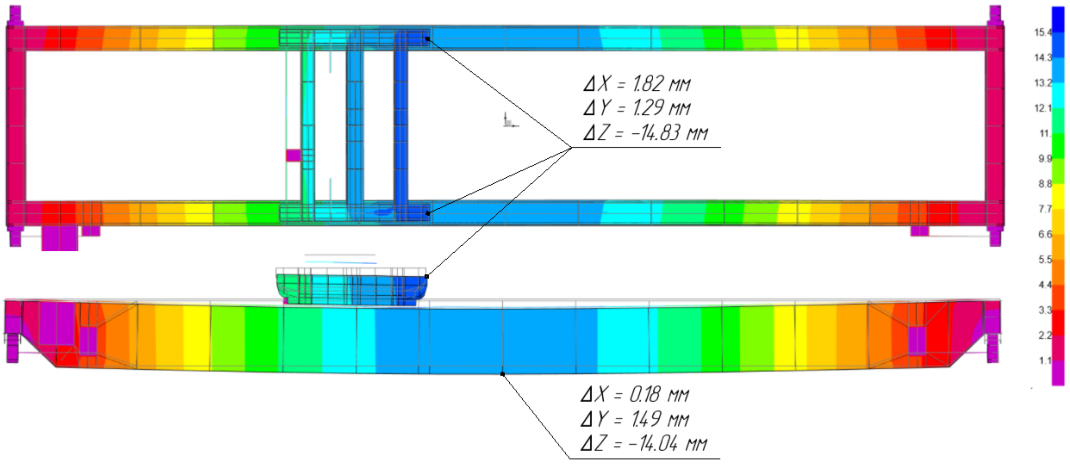

Fig. 1. Deformed state of the bridge crane - static calculation using FEM (illustration by the authors)
Рис. 1. Деформированное состояние мостового крана – статический расчет с использованием МКЭ (иллюстрация авторов)

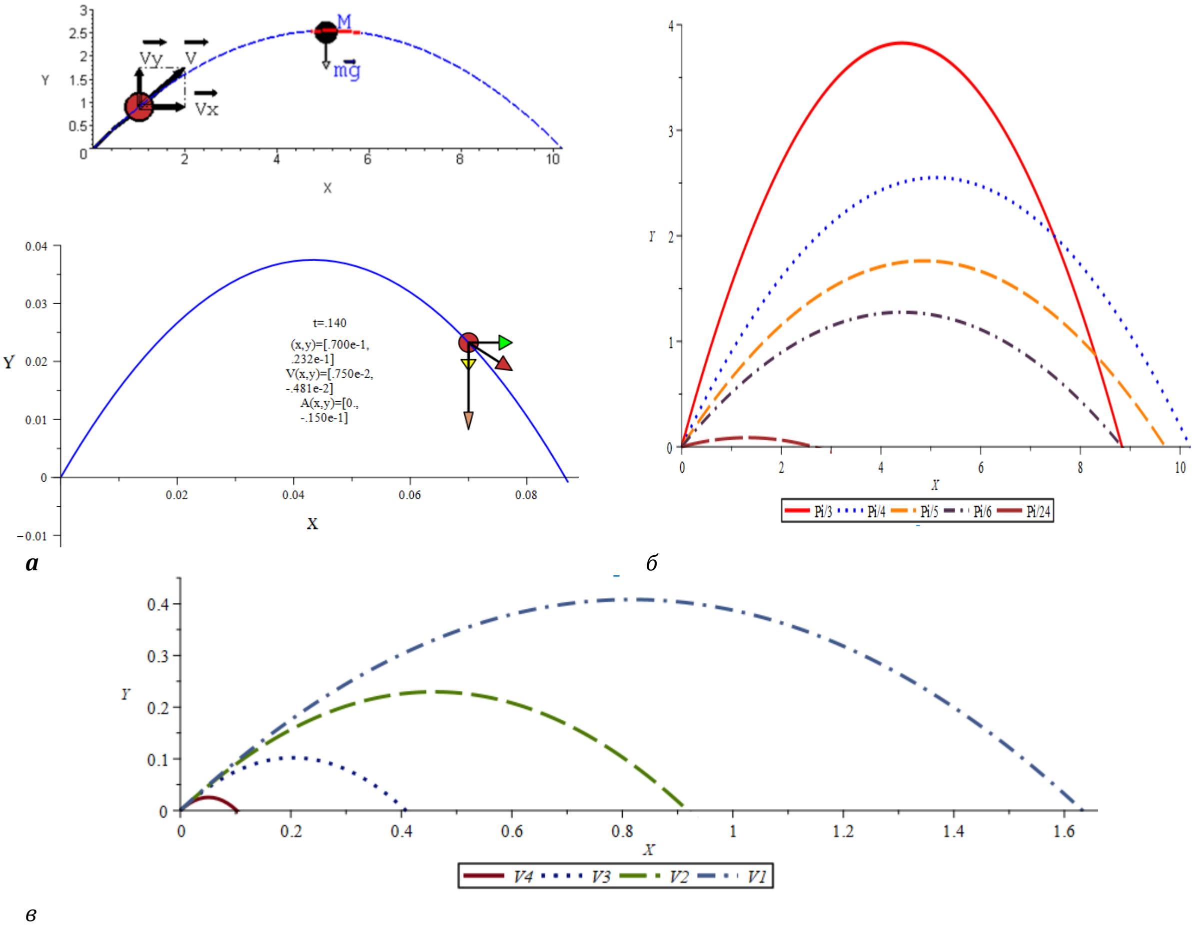

Fig. 2. Example of analytical modeling of the motion of a body thrown at an angle to the horizon [11]:
a – representation of the body and its trajectory; b – influence of the throwing angle on the flight distance;
c – influence of the initial throwing velocity on the flight distance and maximum height (illustration by the authors)
Рис. 2. Пример аналитического моделирования движения тела, брошенного под углом к горизонту:
а – представление тела и его траектории; б – влияние угла броска на дальность полета;
в – влияние начальной скорости броска на дальность по-лета и максимальную высоту (иллюстрация авторов)

FDM is another prevalent numerical method used for solving partial differential equations. In FDM, the studied domain is discretized into a grid, and unlike FEM, the equations are approximated directly at grid nodes using finite differences. FDM is widely applied for hydrodynamics, aerodynamics, heat transfer, and other fields where system behavior can be described by partial differential equations. Examples include modeling fluid flow in pipes, wave propagation in elastic media, and thermal processes in internal combustion engines.

Analytical modeling [7] involves solving mathematical models by deriving analytical expressions that describe system behavior. In mechanics, analytical modeling is used for analyzing relatively simple systems with exact or approximate analytical solutions. Analytical modeling enables the derivation of general behavior patterns and the investigation of parameter influences. Software packages such as MATLAB [8], Mathematica [9], and Maple [10] are commonly utilized, offering extensive tools for symbolic computation, equation solving, graph plotting, and other operations. These packages automate the solving of mathematical models and present results in user-friendly formats. Examples include deriving pendulum motion equations, analyzing spring system oscillations, and calculating the trajectory of a body thrown at an angle to the horizon [1] (fig. 2).

Visualization and animation of mechanical processes are critical components of computer modeling, presenting results in intuitive and comprehensible forms—graphs, diagrams, etc.—that facilitate understanding of system behavior. Animation depicts dynamic processes as sequences of images showing the system's state changes over time. Visualization and animation play a vital role in mechanics education, enabling students to grasp complex concepts and develop an intuitive understanding of mechanical system behavior. Examples include stress distribution visualization in deformable bodies, mechanism movement animation [12] (fig. 3), and fluid flow around streamlined objects.

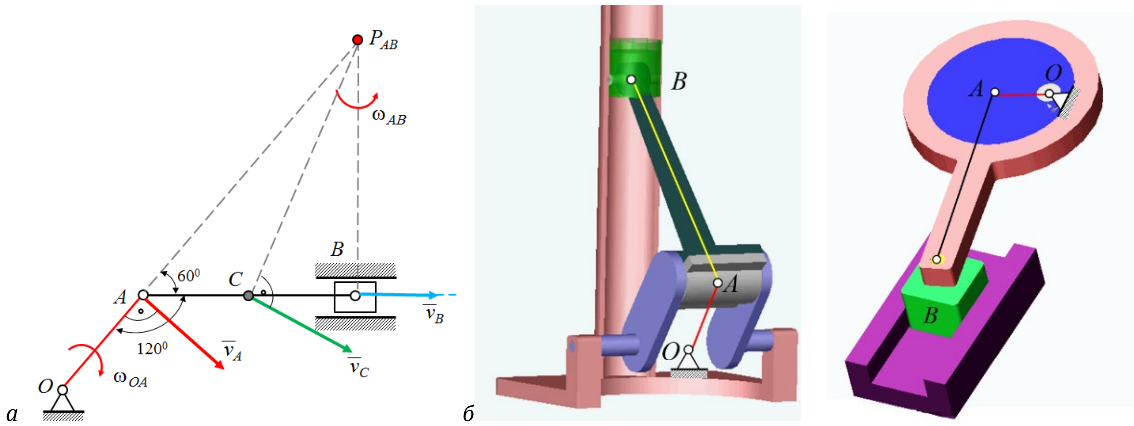

Fig. 3. Animation frames of the crank-slider mechanism:
a – 2D model, b – 3D model (rod-type and round-linkage construction)
(illustration by the authors)
Рис. 3. Кадры анимации кривошипно-ползунного механизма:
а – 2D-модель, б – 3D-модель (стержневая и круглозвенная конструкция)
(иллюстрация авторов)

In conclusion, computer modeling in mechanics is a multifaceted approach encompassing numerical modeling, analytical modeling, and the visualization/animation of mechanical processes. Each method has distinct advantages and limitations, and the choice of technique depends on the nature of the problem and the required result accuracy. Collectively, these methods enable the study of a wide range of mechanical phenomena, making computer modeling an indispensable tool in modern mechanics.

Software for Mechanical Modeling

Currently, a vast array of software exists for computer modeling in mechanics, each with unique capabilities, functionalities, and applications. Broadly, mechanical modeling software can be categorized into several primary groups.

Numerical Modeling Software

This category includes software designed for solving mechanical problems using numerical methods (FEM and FDM) and provides extensive tools for creating geometric models, assigning material properties, defining boundary conditions, performing calculations, and visualizing results: a) ANSYS – one of the most popular and powerful numerical modeling software, widely used in engineering fields including mechanics [13], heat transfer, hydrodynamics, and electromagnetism; offers extensive capabilities for modeling complex mechanical systems, including stress-strain analysis, dynamic analysis, and stability analysis; b) Abaqus – a robust software excelling in nonlinear problem analysis, such as large deformations, material failure, and contact interactions; widely used in automotive, aerospace, and construction industries; c) COMSOL Multiphysics – software focused on multiphysical process modeling, i.e., processes involving multiple simultaneous physical phenomena (e.g., mechanical deformations and heat transfer).

Analytical Modeling Software

This category includes software designed for solving mathematical models analytically and performing symbolic computations, equation solving, and graph plotting: a) MATLAB – widely used for numerical calculations, data analysis, and algorithm development; provides tools for solving differential equations, vibration analysis, etc.; b) Mathematica – software focused on symbolic computations, equation solving, and graph plotting; offers powerful tools for analytical modeling and mathematical model research; c) Maple – software for symbolic computations, equation solving, graph/animation creation; features extensive tools for analytical modeling and mathematical model research [14].

CAD Modeling and Visualization Software

This category includes software for creating geometric models, visualizing simulation results, and generating animations: a) SolidWorks – a popular 3D CAD modeling software widely used in mechanical engineering; offers extensive tools for geometric modeling, assembly design, and result visualization; b) AutoCAD [15] – a popular 2D/3D CAD software widely used in construction and other fields for drawing plans and graphical documents [16, 17].

The selection of specific software depends on the nature of the problem, required result accuracy, available resources, and user expertise. In education, the use of multiple software packages is recommended to provide students with experience in diverse tools and develop skills in selecting appropriate software for specific tasks.

Results. Analysis of Educational Effects of Implementing Computer Modeling

Introducing computer modeling into mechanics education unlocks significant advantages that enhance the assimilation of material, practical skill development, and student motivation. The benefits of computer modeling can be categorized into several key aspects.

One of the most significant advantages is the ability to provide visual representation of complex mechanics concepts and phenomena. Many fundamental mechanics principles, such as rotational dynamics, oscillations, and solid deformations, are described by complex mathematical models that are challenging to visualize without computer modeling. Computer modeling creates dynamic models demonstrating mechanical system behavior in real-time, greatly aiding the understanding of abstract concepts. For example, instead of merely studying pendulum motion equations, students can observe its oscillations in a computer model, adjust parameters, and analyze their effects on motion, facilitating result interpretation and understanding parameter interrelations. Similarly, when analyzing beam deformation under load, students can visualize stress/deformation distribution, better grasping how load influences structural behavior.

Another key advantage is interactivity and experimentation potential. Computer modeling provides an interactive learning environment, enabling students to actively participate in the learning process. Unlike passive lecture attendance and solving standard problems, students can independently investigate mechanical systems, adjust parameters, and observe results, gaining practical experience and developing analytical and problem-solving skills. For instance, while studying projectile motion under a horizontal angle, students can vary initial velocity, launch angle, and other parameters, observing their effects on trajectories and independently exploring ballistics laws [1, 11].

Computer technologies enable simulating real engineering tasks challenging to replicate in labs, such as mechanical systems under extreme loads, complex mechanism dynamics, deformations of building structures [4, 5], and aircraft aerodynamics. Simulating real-world tasks allows students to see theoretical knowledge applications, increasing interest in the subject and motivating deeper study.

Computer modeling fosters problem-analysis and solving skill development, critical for future engineers. Students learn to create models, select appropriate methods, evaluate result accuracy, interpret outcomes, and draw conclusions about system behavior. Additionally, computer modeling enhances proficiency in professional software used in engineering practice, such as ANSYS [18], SolidWorks [19], MATLAB [20], COMSOL [21], Abaqus [22], etc.

Computer modeling accelerates the learning process by providing more visual and interactive material presentation. Students grasp complex concepts and laws faster, gaining practical experience otherwise unattainable via traditional methods, while increased motivation results from a more engaging and interesting learning process. The ability to independently explore and experiment, coupled with visual results, enhances student interest and engagement.

Thus, computer modeling offers significant advantages in mechanics education, including visualization of complex concepts, interactivity and experimentation, real-world task simulation, problem-analysis skill development, and accelerated learning and increased motivation. These advantages make computer modeling an indispensable tool in modern mechanics education, fostering deeper and more effective knowledge assimilation and preparing highly qualified engineers.

Conclusion

The analysis demonstrates that computer modeling is not merely a promising but a necessary tool for modern mechanics, particularly in education, representing a paradigm shift in teaching methodology, providing opportunities previously inaccessible via traditional approaches.

Unlike passive information reception typical of lectures, computer modeling engages students in active learning, enabling them not only to observe mechanical phenomena but also to independently investigate them by adjusting parameters and analyzing results. This approach fosters deeper and durable understanding, as well as critical thinking and analytical skills development.

Implementing computer modeling into the curriculum not only enhances learning quality but also develops skills in demand in modern engineering practice. Working with industry-standard software gives students practical experience crucial for successful professional activity, improving their competitiveness in the job market and aiding adaptation to real working conditions.

Future developments in mechanical computer modeling involve refining numerical methods, developing new algorithms, and creating more powerful and user-friendly software. In particular, multiphysical process modeling methods and integration with virtual/augmented reality technologies are expected to create even more immersive and interactive learning environments.

In conclusion, computer modeling is not a panacea for all education challenges but a powerful tool overcoming many traditional teaching method limitations. Its implementation requires instructors and methodologists to revise curricula and develop new materials, but the achievable results justify these efforts.

Computer modeling fosters deeper and durable understanding, practical skill development, and student motivation, ultimately preparing highly qualified engineers capable of solving complex, non-standard tasks in the context of modern technological progress.

Further development and integration of computer modeling into education is a crucial step toward improving engineering education and training specialists meeting modern world demands.

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КОМПОЗИТНАЯ МЕТРИКА ЭМОЦИОНАЛЬНОЙ КОГЕРЕНТНОСТИ В СИСТЕМАХ ИЗВЛЕЧЕНИЯ КОНТЕКСТА

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Исследование посвящено совершенствованию метрик релевантности эмоционального контекста в системах извлечения контекста для Retrieval-Augmented Generation. Современные подходы фокусируются на семантическом сходстве текстов, пропуская эмоциональную составляющую, когерентность, что критично для задач наиболее точного поиска в эмоционально окрашенных данных. Предложена композитная метрика, объединяющая семантическое сходство векторных эмбеддингов и эмоциональную когерентность, оцениваемую как косинусное сходство текстов. Описана методология вычисления компонент метрики и их взвешивания, на основе которой проведен ряд экспериментов с целью выяснения способности предложенной метрики находить текст более точно, чем модель, основывающаяся на поиске только семантической составляющей. Оценка эффективности проведена на сэмплированном подмножестве датасета Stanford Sentiment Treebank 2 (SST-2). Композитная метрика продемонстрировала более высокую эффективность по метрикам Precision@5, Recall@5, NDCG@5 и MAP по сравнению с методами поиска, основанными исключительно на семантической составляющей. Проведенные эксперименты показали значительный прирост метрик для позитивных и негативных запросов. Проведен дальнейший анализ влияния коэффициентов предложенной метрики. При рассмотрении полученных результатов было установлено, что учет эмоциональной когерентности необходим для достижения оптимальной производительности метрики.

Ключевые слова: *машинное обучение, обработка естественного языка, языковые модели, метрики обработки естественного языка, LLM, эмбеддинги.*

A COMPOSITE METRIC FOR EMOTIONAL COHERENCE IN CONTEXT EXTRACTION SYSTEMS

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The research focuses on improving emotional context relevance metrics in context extraction systems for Retrieval-Augmented Generation (RAG) systems. Current approaches focus on semantic similarity of texts, missing the emotional component, coherence, which is critical for the task of the most accurate retrieval in emotionally colored data. We propose a composite metric that combines semantic similarity of vector embeddings and emotional coherence, evaluated as the cosine similarity of texts. A methodology for computing the components of the metric and weighting them is described, based on which a series of experiments were conducted to find out the ability of the proposed metric to find text more accurately than a model based on semantic component search alone. Performance evaluation was performed