Taras Shevchenko National University of Kyiv

Mechanical-mathematical readings
Autumn session 2024

ABSTRACTS

Kyiv, Ukraine — 2024

Київський національний університет імені Тараса Шевченка

Мехматівські читання
Осіння сесія 2024

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Київ — 2024

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Contents

Clifford algebras of infinite dimensional vector spaces

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We describe derivations of the Clifford algebra associated with a nondegenerate quadratic form on a countable-dimensional vector space over an algebraically closed field of characteristic not equal to 2. Additionally, we construct an algebraic automorphism of the Clifford algebra for a positive definite quadratic form that is not continuous.

Let the Clifford algebra $\mathcal{C}\ell(V,f)$ be generated by a vector space V over a field $\mathbb{F}$ of characteristic not equal to 2, with a unit 1 and defining relations $v^2 = f(v)\cdot 1$, where f is a nondegenerate quadratic form.

Assume the ground field $\mathbb{F}$ is algebraically closed. According to N. Jacobson, if the dimension of the vector space V is even, the Clifford algebra $\mathcal{C}\ell(V,f)$ is isomorphic to a matrix algebra. If the dimension of V is odd, then $\mathcal{C}\ell(V,f)$ is isomorphic to the direct sum of matrix algebras.

Two main families of derivations and automorphisms of Clifford algebras are known:

1. Inner derivations and inner automorphisms.

2. Bogolyubov derivations and Bogolyubov automorphisms.

The Clifford algebra $\mathcal{C}\ell(V,f)$ is graded by the cyclic group of order 2, expressed as

$$\mathcal{C}\ell(V,f) = \mathcal{C}\ell(V,f)_{\bar{0}} + \mathcal{C}\ell(V,f)_{\bar{1}}.$$

A derivation D of the algebra $\mathcal{C}\ell(V,f)$ is called *even* if

$$D(\mathcal{C}\ell(V,f)_{\bar{0}}) \subseteq \mathcal{C}\ell(V,f)_{\bar{0}}, \quad D(\mathcal{C}\ell(V,f)_{\bar{1}}) \subseteq \mathcal{C}\ell(V,f)_{\bar{1}};$$

and *odd* if

$$D(\mathcal{C}\ell(V,f)_{\bar{0}}) \subseteq \mathcal{C}\ell(V,f)_{\bar{1}}, \quad D(\mathcal{C}\ell(V,f)_{\bar{1}}) \subseteq \mathcal{C}\ell(V,f)_{\bar{0}}.$$

Here, we provide a description of the derivations of the Clifford algebra associated with a nondegenerate quadratic form on a countable-dimensional vector space over an algebraically closed field of characteristic not equal to 2. Any nonzero derivation D of $\mathcal{C}\ell(V,f)$ can be uniquely represented as a sum:

$$D = \sum_S \alpha_S \operatorname{ad}(v_S),$$

where $0 \neq \alpha_S \in \mathbb{F}$.

- For an *even* derivation D, the subsets S are finite, nonempty subsets of $\mathbb{N}$ of even order, and each $i \in \mathbb{N}$ belongs to at most finitely many subsets S.

- For an *odd* derivation D, the subsets S are finite subsets of $\mathbb{N}$ of odd order, and each $i \in \mathbb{N}$ lies in all but finitely many subsets S.

Additionally, we characterize when a nonzero even derivation of the Clifford algebra is a Bogolyubov derivation and when a Bogolyubov derivation corresponding to a skew-symmetric linear transformation is an inner derivation.

Now, suppose the field $\mathbb{F} = \mathbb{R}$ is the field of real numbers, and let $f : V \to \mathbb{R}$ be a positive definite quadratic form. In this case, the Clifford algebra $\mathcal{C}\ell(V, f)$ naturally inherits the structure of a normed algebra. In a 2022 MathOverflow discussion, M. Ludewig posed the question of whether every automorphism of $\mathcal{C}\ell(V, f)$ is continuous with respect to this norm.

In response, we construct an algebraic automorphism of $\mathcal{C}\ell(V, f)$ that is not continuous with respect to the given norm.

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Variants of Semigroups

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This talk given on 27.09.2024 was a second part and a logical continuation of a spring session 2024 mechanical-mathematical readings talk presented on 02.02.2024 [1].

Here we studied variants of Rees matrix semigroups over a group G with adjoined 0.

It is obvious that for any fixed $A_{ij} \in \mathcal{M}^0(G; n, m; P)$ the variant $(\mathcal{M}^0(G; n, m; P), *_{A_{ij}})$ is a Rees matrix semigroup but with a sandwich matrix $Q_{ij} = P \cdot A_{ij} \cdot P$.

We studied a property of regularity for Rees matrix semirgoups and variants of such semigroups. Also we found some conditions for such semigroups to be isomorphic.

Theorem 1. *The variant $(\mathcal{M}^0(G; n, m; P), *_{A_{ij}})$ of the semigroup $\mathcal{M}^0(G; n, m; P)$ is regular if and only if the row j and the column i of the matrix P do not contain zero entries.*

Theorem 2. *All regular variants of the semigroup $\mathcal{M}^0(G; n, m; P)$ are pairwise isomorphic.*

Further we consider a Rees matrix semigroup over a trivial group with zero $G^0 = \{0, 1\}$

Theorem 3. *Let the matrix $\widetilde{P}$ be obtained from the matrix P by permutation of rows and columns, then Rees semigroups $\mathcal{M}^0(G; n, m; P)$ and $\mathcal{M}^0(G; n, m; \widetilde{P})$ are isomorphic.*

Theorem 4. *Variants $S_1 = (\mathcal{M}^0(G; n, m; P), *_{A_{ij}})$ and $S_2 = (\mathcal{M}^0(G; n, m; P), *_{A_{lk}})$ are isomorphic if and only if their sandwich matrices Q_{ij} and Q_{lk} after delation of null-rows and null-columns are coincide.*

1. Desiateryk O. O. Sandwich Semigroups Isomorphisms. Mechanical-mathematical readings, Spring session 2024, ABSTRACTS, Kyiv, Ukraine, 2024, p. 8.

Machine learning, field overview

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This talk provides a high-level overview of the current state of the field of machine learning. It includes a brief historical background, an overview of classical algorithms, and the main principles of machine learning. Following this, we will discuss the differences between machine learning, artificial intelligence, and data science.

The second part of the talk will focus on deep learning, neural networks, and modern AI systems. Finally, we will present a series of contemporary mathematical methods used in machine learning, particularly in generative learning. We will also demonstrate how machine learning methods can contribute to classical mathematical research, such as solving differential equations and applied statistical analysis.

Fundamental Regularities of Propagation of Elastic Waves

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The report is dedicated to establishing new and analyzing a series of known specific laws of wave propagation in elastic bodies that have no analogue in acoustics and electrodynamics. In particular, the focus is on identifying the physical reasons for such non-trivial effects as resonances on inhomogeneous waves based on the analysis of the characteristics of the transformation of longitudinal and transverse waves at boundary surfaces.

Based on the analysis of the wave field excited by the first normal wave incident on the free end of an elastic half-layer with free lateral surfaces, the features of resonance on inhomogeneous waves during symmetric oscillations are analyzed. In general, in an elastic body of arbitrary shape, the wave field can be represented as a sum of longitudinal (P) and transverse (SV) waves. For the first normal wave in the far field, the SV component propagates through the thickness of the layer, while the P component is non-uniform with respect to the thickness coordinate. At the same time, upon reflection of the SV component from the free end, in the vicinity of the frequency of the edge resonance, a P-wave that propagates appears. This mismatch between the structure of the near and far fields results in significant excitation of inhomogeneous waves at a certain frequency. The proposed qualitative analysis of significant excitation of inhomogeneous waves at a certain frequency is confirmed by quantitative calculations [1].

Resonance on inhomogeneous waves during antisymmetric oscillations was first discovered. The main differences in resonance depending on the symmetry of the oscillations have been established. Another specific effect of elastic wave propagation is the frequency dependence of the transparency of a limited boundary between elastic bodies.

Based on the solution of the boundary problem of exciting a wave field in an elastic isotropic composite waveguide formed by the rigid contact of two half-layers with different mechanical properties and the same width or the same mechanical characteristics but different widths, conditions have been found under which a sharp decrease in the reflected field occurs at a certain frequency, which is caused by significant excitation of inhomogeneous waves. At this frequency, intense oscillations occur, localized in the vicinity of the interface. According to this feature, this effect can be considered as a generalization of the concept of edge resonance in the case of composite waveguides [2].

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2. Gorodetskaya N., Starovoit I., Sobol T., Shcherbak T. The Influence of the Symmtry of Oscillations and the Ratio of yhe Half-Layer Widths on the Transparency of the Boundary in a Stepped Waveguide. *Science-Based Technologies.* 2022, 55, ¹ 3, P. 244–253. DOI: 10.18372/2310-5461.55.16907

Stability, Lyapunov functions, and neural networks

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The report discusses some results from [1] concerning application of deep neural networks in the qualitative theory of differential equations. The main focus is on the methodology and computing of approximate Lyapunov functions of large-dimensional systems of nonlinear ordinary differential equations.

1. Grune L. Computing Lyapunov functions using deep neural networks. Journal of Computational Dynamics, 2021, 8(2), 131-152.

Peculiarities of the behavior of solutions to boundary value problems in potential theory and elasticity theory in domains with angular points

Dedicated to the memory of the Great Scientist and Teacher A.F. ULITKO on the occasion of his 90th anniversary

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If we need to solve a bounbary value of the potential theory or the theory of elasticity in a domain, which boundary has irregular points, the first step is s to determine the peculiarities of the behavior of the desired solution near these singular points. This information is essential both for constructing an exact solution using analytical methods and for applying approximate methods to solve the problems. Depending on the geometry of the domain near the singular point and the type of boundary conditions, the desired solution may have singularities of various forms. It should be noted that in his scientific work A.F. Ulitko paid considerable attention to these problems, and together with his students achieved significant results [1, 2, 3].

The report examines examples of certain 2d and 3d problems of the potential theory and the theory of elasticity, which involve mathematical tools enabling to determine of the behavior of solutions near angular points of domains. These examples demonstrate that, in the 2d case, determining the nature of the singularity can be accomplished using the method of separation of variables, after which the problem is reduced to solving a transcendental equation, which is called the characteristic equation. The roots of the characteristic equations that correspond to potential theory problems have only real roots. Therefore, solutions of 2d potential theory problems at corner points can only have power singularities. In the case of 2d elasticity theory problems, the corresponding characteristic equations can have both real and complex-conjugate roots. Therefore, depending on the boundary conditions and the angle of opening, the solution may exhibit either a real power-law singularity or a complex one. The latter gives rise to the so-called oscillatory singularity in the solution.

In the 3d case, particularly in exterior problems, the method for determining the singularity of the solution becomes significantly more complicated. In such problems, the method of separation of variables can no longer be applied. In the problem of determining the singularity of the potential field at the vertex of a trihedral angle, it was necessary to use the method of integral transforms in conjunction with the Wiener-Hopf method. As a result, it was established that at the vertex of a trihedral angle, the potential field exhibits a real power-law singularity, the exponent of which significantly depends on the geometric parameters of the angle.

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Statistics of Mixtures with Varying Concentrations

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In the communication we consider statistical techniques based on the finite mixture model (FMM) and the model of mixture with varying concentrations (MVC). Both FMMs and MVC are widely used in the statistical analysis of medical, biological and sociological data [1,3,4].

As an example of nonparametric MVC models we consider a two-component model in which the observed data ξ_1, ξ_2,..., ξ_n are independent random variables with the distributions [2]:

$$\mathbf{P}\{\xi_j < x\} = p_j(\vartheta)F_1(x) + (1 - p_j(\vartheta))F_2(x),$$

where F_1, F_2 are completely unknown distribution functions of the mixture components, $p_j(\vartheta)$ is the concentration of the first component in the mixture at the j-th observation. The function $p_j(\vartheta)$ is known up to an unknown parameter $\vartheta \in \Theta \subseteq \mathbf{R}^d$.

A least squares estimator (LSE) and an empirical maximum likelihood estimator (EMLE) are considered. We compare these estimators performance via simulations.

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On a Finite Automaton Representation of $GL(n, \mathbb{Z})$

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Let $\mathcal{T}_n$, $n > 1$, be a rooted n-regular tree, $Aut\mathcal{T}_n$ be the automorphism group of $\mathcal{T}_n$ Denote by $FAut\mathcal{T}_n$ the subgroup of $Aut\mathcal{T}_n$ of all finite state automorphisms of $\mathcal{T}_n$ (for details, see [1]).

In [2] for every $n \geqslant 2$ the authors constructed an isomorphic embedding

$$\varphi_n : GL(n, \mathbb{Z}) \to FAut\mathcal{T}_{2^n}.$$

Using embedding φ_2 it is constructively shown that the following statement holds.

Theorem. *There exist two automorphisms $f, g \in FAut\mathcal{T}_2$, each with 9 states, such that the subgroup $\langle f, g \rangle$ is free of rank 2.*

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Models of time-changed stochastic processes

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Stochastic processes with random time-change attract more and more attention in recent literature due to their various applications in financial, biological, ecological, physical, technical and other fields of research.

The generalized counting process $M(t)$, $t \geqslant 0$, and its fractional extensions were introduced and studied in [3]. The probabilities $p_n(t) = \mathrm{P}\{M(t) = n\}$ depend on k parameters $\lambda_1, \dots, \lambda_k$ and are given by the formula

$$p_n(t) = \sum_{\Omega(k,n)} \prod_{j=1}^{k} \frac{(\lambda_j t)^{x_j}}{x_j!} e^{-\Lambda t}, n \geqslant 0,$$

where $\Omega(k,n) = \left\{(x_1, \dots, x_k) : \sum_{j=1}^{k} j x_j = n, x_j \in N_0\right\}$, $\Lambda = \sum_{j=1}^{k} \lambda_j$. This process performs k kinds of jumps of amplitude $1, 2, \dots, k$ with rates $\lambda_1, \dots, \lambda_k$. Such processes are of interest for various applications, in particular, in risk theory.

In the talk we consider generalized counting processes with double time-change by means of an arbitrary subordinator and an inverse to another subordinator, we characterize their distributions and present governing equations for them, which are derived following the technique presented in [1]. The equations are given in terms of the generalized Caputo-Djrbashian derivatives, which are called also convolution-type derivatives with respect to Bernštein functions. Some particular examples are presented. The talk is based on the paper [2].

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Instruction detection system for cyber protection without trust in heterogeneous networks

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Relevance. The Internet of Things (IoT) and the Industrial Internet of Things (IIoT) and their widespread application make them attractive targets for cyber attacks. Traditional cybersecurity methods such as firewalls and antivirus software are not always effective in protecting IoT/IIoT networks due to their heterogeneity and large number of connected devices. The zero-trust principle can be more effective in protecting IoT/IIoT networks. This principle assumes on no inherent trustworthiness of any user, device, or traffic, requiring authorization and verification before accessing any network resource.

This report presents a zero-trust-based intrusion detection system (IDS) that uses machine learning to secure IoT/IIoT networks. The aim of this report is to develop a two-component IDS for detecting and classifying cyber-attacks. The study utilizes machine learning techniques, such as Decision Tree, Random Forest, and XGBoost, on the Edge-IIoTset dataset.

The following results were obtained. The IDS structure proposed here employs a sequential approach that consists of two AI modules. The first module detects attacks using a simpler model like Decision Tree. The second module uses more complex models like Random Forest or XGBoost to classify attack types. Experimental evaluation on the Edge-IIoTset dataset demonstrates the system's effectiveness, with an overall accuracy of 95

The proposed design for an Intrusion Detection System (IDS) achieves high accuracy in detecting attacks while maintaining optimal performance and minimizing additional computational costs. This is especially crucial for real-time network monitoring in IoT/IIoT environments

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2. 2. Valentyn Sobchuk, Roman Pykhnivskyi, Vitalii Savchenko, Andrii Sobchuk, Bogdan Stepanchenko, Andrii Pankov The Method of Ensuring Functional Stability by Means of Sequential IDS for Cyber Protection Without Trust of IoT/IIoT Networks // 2024 IEEE 5th International Conference on Advanced Trends in Information Theory ATIT-2024, 20.11.2024

Stochastic differential equations in infinite dimentional spaces

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The report is an overview of stochastic differential equations in infinite dimensional spaces. More precisely, we consider the following equation

$$dX = (AX + F(t, X))dt + B(t, X)dW(t) \tag{1}$$

Here A is the linear unbounded operator from some Hilbert space H to H, $F : H \to H$, $B : H \to L_2(Q^{\frac{1}{2}}(H), H)$, $W(t)$ is infinite dimentional $Q-$ Wiener process. Different approaches to defining a solution are discussed. Corresponding existence and uniqueness theorems are given. Examples of specific equations are also demonstrated.

Mechanics of Conjugate Fields In the Scientific Heritage of A.F. Ulitko

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This communication was dedicated to the 90th anniversary of the outstanding Ukrainian mechanician and mathematician professor Andriy Ulitko (1934-2015), who contributed much to the development of the Faculty of Mechanics and Mathematics and the Institute of Mechanics in his time. Starting from the Academy of Sciences and later at the University, he founded the scientific school of mechanics of conjugated wave fields in materials with piezoelectric properties and structural elements made of them. His theory of electroelasticity in due time became an ideal of a perfect mathematical field theory in solid mechanics.

Significant success in this field was due to the fact that A. F. Ulitko creatively perceived and thoroughly developed the scientific ideas of his prominent teachers – academician prof. Anatoly Kovalenko (1905-1973) and corresponding member prof. Georgy Polozhii (1914-1968). From the first of them, A. F. Ulitko received scientific ideas of a complex analysis of conjugate fields in boundary value problems of non-stationary thermoelasticity, performing complex calculations of thermal stresses in elements of rocket engines. The second prompted A. F. Ulitko to create an invaluable mathematical apparatus of the theory of eigenvector functions in spatial problems of the theory of elasticity. The topic of analytical solutions of boundary value problems was of great importance in due time: the fact is that in the 1960s, neither powerful computers nor comprehensive computer methods existed. On the other hand, what the computer could not provide, these gaps, had to be filled with hard intellectual work: "sheets"of handwritten formulas and a dozen reference books were always present on Andriy Ulitko's desk.

The most important A.F. Ulitko's scientific achievements in the mechanics of conjugate fields include:

- development of the foundations of mechanics of conjugate static and dynamic fields in piezoelectric solids at the level of vector boundary value problems;
- theory of arbitrary spatial motion of elastic solids in the form of conjugate vector equations of dymamics and boundary conditions in mooving reference frame;
- theory of electromechanical energy conversion in arbitrary deformed piezoelectric solids and the theory of electric discharge of piezolectric transducers, both of them based on comrehensive solution of boundary value problems of electroelasticity;
- development of mathematical methods of the analysis of dynamic characteristics of microwave (ultrasound) actuators and solid state wave gyroscopes;
- extension of the developed mathematical methods to the solution of contact problems of the theory of elasticity;
- solution of conjugate problems of thermoelectroelasticity.

The scientific works of A.F. Ulitko have gained world recognition. The scientific achievements of the staff of the A.F. Ulitko scientific school are reflected in more than 800 publications in leading domestic and foreign journals, in dozens of monographs and textbooks.

Active Vibration Control of Layered Thin-Walled Structural Elements with Hiezoelectric Layers

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The forced-vibration analysis of structures occupies a significant place in the dynamics of deformable systems. An accurate prediction of the dynamic response is a serious challenge, since the material of a structure may become plastic under intensive loading and/or exhibit viscous properties. Variable viscoelastoplastic behaviour should be studied when designing metal dampers for the vibrations of building structures under wind and seismic loads, devices for suppressing vibrations of pipelines, test specimens in low-cycle fatigue tests, etc.

A modern approach to controlling the vibrations of complex systems suggests introducing additional active elements into a structure being designed. It was demonstrated that distributed piezoelectric elements are efficient in damping vibrations of elastic plates and shells. The overall aim of this research is to improve our understanding of the complex coupled processes in thin-wall inelastic structures that contain both active and passive layers and experience intensive cyclic loading. We analyse the role that the coupling of mechanical and electrical fields can play in defining the structure response. For this purpose, a simplified single-frequency approach is developed to describe the coupled dynamic behaviour under cyclic electric or mechanical loading of layered shells consisting of physically nonlinear passive and viscoelastic active layers [1]. The period averaged dissipative function obtained from the solution for steady-state vibration problem is used to simulate the internal heat sources. Substitution of the dissipative function into the heat-conductivity equation averaged over the period of vibration enables us to address the heating aspect of the problem and estimate the temperature level to prevent the overheating above the Curie point for the piezoelectric material [1,2].

As an example, the problem of forced vibrations of a roller supported beam containing piezoactive layers is solved [3]. Different aspects of mechanical and electric excitation of the vibration are studied as well as the possibility of suppressing the mechanically induced vibration by means of voltage application to electrodes at the piezoactive layer. The interplay between physical and geometrical nonlinearities under transient and steady state processes is investigated. For the mechanically excited vibrations, when piezoelectric layers work as sensors, the electric response of partially depolarised (due to excessive heating above Curie point) beam is considered. The low cycle structural fatigue curves with respect to the temperature are plotted and safe regimes are determined. The temperature histories are also analysed for the case when the harmonically varied voltage supplied to piezoactive layers suppresses the mechanically excited vibrations. The single frequency approximation was proved to be an accurate enough and reliable tool for temperature estimation even in the vibration suppression regime when the temperature of dissipative self-heating can reach significant levels due to the dielectric losses in piezoelectric layers. The developed technique is much faster, and demands less computational resources, than approaches involving direct integration of the complicated constitutive equations.

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Notes on the scientific heritage of Andriy Feofanovich Ulitko. Part 1

Dedicated to the memory of the Great Scientist and Teacher A.F. Ulitko on the occasion of his 90th anniversary

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The report attempts to analyze the scientific achievements of Corresponding Member of the NAS of Ukraine, Professor Andriy Feofanovich Ulitko, based on his publications from 1960 to 1990.

Andriy Feofanovych was the extremely talented and hardworking scientist and left behind a multifaceted and numerous scientific heritage, covering most of the sections of mechanics, mathematical physics and complex analysis. Therefore, it is quite difficult to evaluate all the scientific achievements, which, of course, are still relevant in our time. The report should be perceived only as an attempt to conduct at least a partial systematization of Andriy Feofanovych's scientific interests, their logical connection with professional activities. This report is also important for assessing the impact of Andriy Feofanovych's activities on the formation of scientific thought in the educational and scientific environment in the field of mechanics in Ukraine at that time. A number of new and promising sections of mechanics are associated with the name of Andriy Feofanovych Ulitko. He created his own scientific school, whose representatives are still making a significant contribution to the development of science and education in modern Ukraine.

The report systematizes the sections of mechanics in which Andrey Feofanovich's publications have proven to be important. A number of publications that have become classics in our time are highlighted, publications that contain ideas that, in the author's opinion, are undervalued and have good prospects for continuation and development, publications that contain paradoxical results in some sense. In particular, three articles are carefully analyzed, which, in the opinion of the author of the report, most vividly characterize the style and depth of Andrey Feofanovich's scientific intuition. The report also analyzes references to scientific works that largely reflect the level and breadth of Andrey Feofanovich's coverage of the ideas of both classical and modern mechanics-mathematics.

The report is based on 121 publications by Andriy Feofanovich (monographs, textbooks, scientific articles, abstracts of reports at scientific conferences), on communication with Andriy Feofanovich's colleagues, and on the author's personal experience of communicating with Andriy Feofanovich, who was lucky enough to be Andriy Feofanovich's student and work alongside him since 1980.

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Mechanical-mathematical readings
Autumn session 2024

ABSTRACTS

Kyiv, Ukraine — 2024

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Мехматівські читання
Осіння сесія 2024

ТЕЗИ ДОПОВІДЕЙ

Київ — 2024

Комп'ютерна верстка
Д.О. Іванова