**Vibration Control Strategies for Smart Transportation Systems: from Theory to Practice**

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**Abstract:** Strategies for vibration control are paramount across disciplines including civil, structural, mechanical, and aerospace engineering. For smart transportation systems, vibration significantly influences ride safety and comfort, necessitating effective mitigation techniques. This research investigates vibration-control strategies for such systems, encompassing all levels of traffic from light to heavy loads, and addresses single vehicles, multiple vehicles, or combinations of both. The study formulates mathematical models for the transportation systems and derives algorithms that implement well-established active, semi-active, and passive vibration-control strategies, exemplified by the Linear Quadratic Regulator, Skyhook, and inerter designs, respectively. Utilizing these algorithms, a dedicated simulation tool is developed to predict vibration-control performance and optimize associated parameters. Both simulated and experimental results demonstrate that the employed strategies can substantially attenuate vibration responses. The research therefore provides both conceptual foundation and practical guidance for applying vibration-control techniques to smart transportation systems

**Keywords:** Vibration control, transportation systems, active control, passive control, continuous systems, smart materials.

**INTRODUCTION**

Vibration control underpins the innovation waves in smart transportation systems by fostering higher transit efficiency. Intelligent transportation systems adapt traffic flows, routes, and terminals based on real-time or historic data [1]. The integration of various vibration control methods 6 active, semi-active, hybrid, and passive devices 6 can suppress noise, energy waste, wear, tear, and fatigue that compromise structural integrity. Adapting vibration-control solutions to specific structural patterns, traffic, and environmental conditions facilitates the development of operation-friendly, cost-effective, and computationally viable processes [2]. Deployable systems can reposition over time for optimized performance. System identification leveraging the mobility of unmanned ground vehicles alongside force generation of electromechanical devices enables input-output data acquisition. While linear models constitute initial approximations, incorporating the nonlinearities of dynamic interactions promises improved accuracy.

In recent decades, the advent of smart transportation technology has accelerated the development of its various systems. The design of an entire vibration control strategy that fully exploits the capabilities of smart transportation is a critical topic. This investigation provides a comprehensive examination of vibration control systems for smart transportation from the viewpoint of theory to practice, with a strong emphasis on the theory. The fundamental aspect of vibration control and the construction of a general strategy are thoroughly analysed. Different types of vibration control systems—active, passive and combined—are systematically discussed with regard to smart transportation applications. Selected design techniques for vibration control systems are presented, including mathematical models and simulation procedures. Realistic results from tests and operations are used to quantitatively demonstrate the vibration control systems and to examine the effectiveness of the proposed theoretical methods. The purity of operation and the rationality of control defined in this study contribute to the establishment of state-of-the-art vibration control for smart transportation. Additional components are included to ensure the overall coherence of the material.

Advanced operational benefits are provided through intelligent transportation systems with enhanced models, integrated traffic management, and innovative commercial vehicle operations. Hierarchical Network Structure A railway transportation system with hierarchical network structure represents a multilayer design, and it separates the two-layer mechanisms (i.e., incurring costs) between infrastructure adjustment and operational management thereby improving actual operation of the network. This enables the aggregation of diverse data sources to efficiently control nascent transport systems and acceptance of disperse control inputs from multiple origins (including prioritization of manual control action under emergency conditions). In Brief: Swarm-based traffic optimization in the presence of automatic control shows better performance, including reduced traffic density, less fuel consumption and higher safety. For mathematical models to determine the optimum value according to the specific condition. Adaptive scheme to actively and instantaneously suppress the remained longitudinal vibrations inside vehicles using recursive least squares algorithms, conducted by placing active isolators in the suspension components of the vehicle; where on-line update decides its working condition according to the operational status of the vehicle, extracts structural behavior, and confirmed source information of longitudinal vibrations. These approaches have been proven effective through simulations and experimental tests [1] [2].

Dynamic response of structures is a common feature in many types mechanical components and constructions. In the field of transportation, vibrations are expressed as structure borne vibration and vehicular vibration. Health hazards, which were divided into noise-induced and vibration-induced health hazard effects, included engine noise; gearbox vibration; vehicle (from road roughness irregularities) and air craft take-off and landing. Vehicle vibrations are further divided into vibrations of running vehicles, bus and train for example, and vibration of parts mounted in them like frame or engine. The interaction among these vibration sources plays an important role in the dynamics of transportation systems [3, 4] [2].

The advent of all modes of transportation-such as the bus, the subway, the train, the ship, airplane, satellite and spacecraft--represents a continual attempt to make travel more convenient. But the extension of transportation networks is also a cause of increased exposure to environmental disturbances that, if not properly managed, may deteriorate the performance and passengers travel comfort.

Accordingly, in modern transport projects lot of solutions are being implemented about vibration reduction against excessive oscillations. Even if a great deal has been achieved with respect to the development of analysis and design tools, the basic principles characterizing vibration have changed very little across years.

Vibration affects all area of technology and it is mainly caused by the external excitations applied to a system (for instance, road vehicles going over an uneven road/surface or train on roughened rail track) [4]. The vibration indicates the motion of a structure from its equilibrium position and buildings and vehicles provide a good number of degrees of freedom. Rotating or unbalanced components can induce vibration into a system. For instance, an excited two degree-of-freedom mass on a spring system generates substantial vibration coupled with two resonance frequencies. The response of structures to varying loading conditions closely relates to their natural modes of vibration and natural frequencies. When external loading frequency matches the structure’s natural frequency, resonance occurs, potentially leading to extreme displacements. Vibration also manifests as oscillatory behavior on structural members [2].

Vibration is the repetitive to-and-fro motion of a system of particles about a mean position of equilibrium. It is an integral part of the natural frequencies of any physical structure. Materials, such as mechanical, hydraulic, pneumatic, and electrical components, encounter a wide variety of vibration manifestations. The vibrations encountered in transportation are classified into three types [3] : translations, rotations, and free vibrations. Translational vibration occurs when a car moves from one place to another, such as a landing of an airplane, vehicle moving on a rough road, or a railroad car on a disturbed track. Rotational vibration causes a car to oscillate about a common axis of rotation, and it usually lasts only a few seconds. Rotational vibration appears when the vehicle bounces over a bump causing the car to rotate on one of the front wheels. Free vibration is the displacement of the system without external pallet action. It occurs when a system oscillates at its natural frequency after it has been disturbed by an external force [4].

**METHODS**

Transportation has a long history of exciting innovations and also brings many concerns about undesirable vibrations. Vibration control strategies can be deployed to mitigate the negative impacts, which, within the smart transportation paradigm, ultimately improve user experience and also enhance system efficiencies. They can generally be subdivided into three categories, i.e., active, passive and hybrid arrangements [4]. Their principles and respective features are briefly reviewed in the following.

Active vibration control makes use of actuators and energy supply devices to generate countering excitation forces and suppress the induced vibration. Owing to the requirement of implementation, it is regarded to have high cost and potentially impaired reliability [1]. This methodology is therefore more adapted to vibration control scenarios where the displacement involved is small and there exist stringent conditions such as prevention of additional friction, low energy consumption or low noise level. Representative embodiments include hydraulic, piezoelectric and pneumatic systems.

Passive vibration control instead relies on the introduction of auxiliary elements (e.g. springs, masses, dampers) to attenuate the transmission or transformation of undesirable fluctuations. The resulting arrangements are more compact and require no power supply. Nevertheless, owing to absence of capacity for energy input, they are unable to manipulate vibration when the applied excitation is changed. Additionally, the lack of sensing and operation flexibility imposes considerable limitations in efficiency and performance [3]. Typical configurations cover tuned mass dampers, base isolation systems, energy absorbers and friction dampers.

Hybrid strategies combine the advantages of both active and passive solutions; for instance, semi-active control is largely regarded as the best vibration control approach and has been successfully applied to a variety of transportation systems. Typically, the configuration subscribes damping devices with tunable properties and adjusts the system response according to the constructed control scheme and, quite often, the information captured in real time. This results in high performance and reduced power consumption without posing a threat to the controllability or the overall system integrity.

It should be noted that the different strategies mentioned above are not intrinsically limited to certain applications but can be adapted to various systems according to the requirements in practice. To assess implementation of the vibration control techniques, mathematical models and numerical algorithms (Section 2.4) can be constructed and subsequently verified with physical devices (Section 2.5). Semi-active control intervention in particular can be integrated to smart transportation components and resourcefully combined with other control measures to provide optimized modulation at the system level (Section 2.6).

With active control, it is therefore possible to dynamically and more optimally address these issues in a way that has not been achieved through passive devices due to the inability to respond (in real time) to changing vibration inputs. In this method, sensors are assumed to be installed on the external disturbances and structural response continuously. The data obtained is analyzed using optimal control algorithm software on a computer controller, for one thing its suitable force inputs to plant in the form of actuator control forces. Contrary to passive systems, active control introduces directly the mechanical energy to the structure and governs its behaviour. The control policy can be categorized as feedback active vibration control when only a response variable is observed, feedforward active vibration control when only the external excitation is measured and fed back into the system and feedback-feedforward (Hybrid)active vibration control when both responses are monitored. Application of active control Schemes Active control strategies have proved to be successful in seismic isolation and the reduction of traffic-induced vibrations, such as those caused by heavy trucks on bridges [1]. Several active control strategies such as the application of fluid viscous dampers, tuned mass dampers and magnetorheological devices have been studied for the stabilization in beams [4–7], high-speed railway bridges [8] and vehicles. A control scheme involving feedback, neural networks and hybrid arrangements allows for an improved performance of the structure under dynamic loadings [3].

Passive control techniques for structural vibration mitigation do not require an external power source or electronic devices for operation. They are the most commonly adopted devices for reducing excessive vibration and improving structural safety [1] [3]. Nevertheless, after installation, the parameters of passive devices are fixed and cannot be modulated based on real-time vibration frequencies and magnitudes. It is therefore necessary to establish a reliable estimation of the design load and a clear understanding of the dynamic properties of the structure before implementing passive control elements. Passive damping is typically added through fluid viscous dampers, friction dampers, tuned mass dampers, and base isolation systems. Semi-active control techniques are a relatively new development. Unlike active controls, semi-active methods do not add mechanical energy to the system, and contrary to passive controls, their properties can be changed under real-time vibration conditions. Consequently, semi-active devices combine the advantages of both passive and active systems.

Hybrid isolation systems that share active and passive aspects are proposed for vibration reduction over a frequency band [2]. Hybrid systems combine certain passive elements and active actuators to utilize the benefits of two types. An active system is able to produce large forces but at the expense of power and complexity and a passive system is naturally robust but restricted in bandwidth and tunability; hybrid combinations attempt to find a compromise between these two extremes. Both analytically and numerically, we illustrate the key features of parallel hybrid mechanisms that consist of both passive and active elements in a unified design approach: the output from the hybrid equals to be sum of its active and passive components set up in parallel.

By providing the best features of the respective guiding mechanisms, better guidance performance can be obtained by hybrid systems. They also have the ability to compromise between fabrication in an active and a passive mode, making it impossible in strictly passive or strictly active configurations. The hybrid that can achieve the high level force broad banding of active control and the robustness and ease of passive approaches.

The modeling of smart structures requires the development of reliable mechanical and mathematical models to reproduce the dynamic behavior of the system in different excitation scenarios. These models allow the prediction and simulation of the control, which avoids expensive experimental tests and enables the identification of the main parameters to improve the system and its regulation [2]. Simulation tools are useful to determine the vibration level on a structure for a given vehicle velocity as well as to size a vibration control system with a desired performance level.

Basic models of interaction vehicle-bridge are presented from a computational point of view to the formulation of the mathematical equations that describe the dynamic behavior of the system. Some finite element methods used to characterize the dynamic response of viaducts when the train runs on the bridge are then indicated [5]. Analytical models are described and assembled into a commercial finite element program for the dynamic analysis of railway bridge/track/train systems. Vehicle and bridge can be modeled as multi-degree-of-freedom systems. Theirs linear motions are coupled through an un-sprung-mass entity.

The pulse signal recognition theory with the pulse matching method is also applied to identify disturbances and extract pulse signals from a vibration signal. Finally, the application of the correct control strategies considerably minimizes energy consumption.

Mathematical models and simulation tools provide effective means to predict and optimize vibration-control-performance efficacy. Active-mass dampers and electromagnetic systems are widely applied in active-vibration-mitigation of dynamic structures. Model-predictive-vibration-control and constrained-MPC techniques demonstrate efficacy on lightly damped mechanical systems. Sufficient-transient-response and output-constraints are articulated for controlled dynamic performance. MPC implementation refers to nonlinear ACADO-toolkit for automatic control and dynamic-optimization, enabling efficient real-time solution of the underlying nonlinear program. LMI-based H∞ is applied for an active suspension in full-vehicle model, optimizing control robustness, passenger comfort, and road holding. Active control approaches are benchmarked against passive strategy in the context of WPV. Optimal sensor and actuator locations support effective vibration control. The choice between fixed layout and reconfigurability is critical to system power-consumption and task-adaptation. Probabilistic localizations and semantic-mapping techniques facilitate a Global-Positioning approach. In innovative configurations, manufactured carbon-fiber reinforced polymers enable lightweight and tailorable-systems integration. Vibration-control-strategies offer spatial-applicability in reaching diverse targets through multiple pathways [9-15].

Modeling and simulation plays a key role in the development of vibration control designs for smart transportation systems. Models developed on the basis of physical principles that govern vibration phenomena provide a way to predict system behavior. Simulation software allows analysis of control strategies before they are implemented in the field and for a wide variety of layouts and operating conditions [2]. The construction of mathematical models begins with a version in which the system is uncoupled. For a cantilever beam under an external disturbance, the equation of motion can be given by θ̈ + 2αθ̇ + ω θ =τ (t), where θ denotes system response, α is damping ratio and ω is natural frequency, τ(t) stands for external disturbance. Actuation torque may be added to handle the control inputs. To facilitate the control synthesis, a state-space representation of the system is employed by choosing as states x = [θ θ̇]ᵀ and leading to first-order differential equations describing the dynamics— (10) where u(t) is treated as an input.

Simulation software aids in optimizing control parameters, comparing different control approaches, and simulating the system performance under specified conditions. Simulation tools of practical utility encompass MATLAB, MSC ADAMS, CarSim, and SIMPACK. MATLAB facilitates the implementation of various control designs and the simulation of system dynamics. Components based on the precise geometry of the system can be imported into MSC ADAMS to calculate dynamic responses, which can be coupled with MATLAB to incorporate active control. CarSim specializes in the simulation of vehicle dynamics, while SIMPACK functions as a multibody simulation program. Relevant control models can be implemented to predict the efficacy of anticipated control strategies.

**RESULTS**

As the vibration control strategies, modeling and simulation research conducted in Sections 2.3 and 2.4 have demonstrated, there is a demonstrated capability to reduce vibrations during transportation processes, as being the principal source of information for the design of experimental verification. During a two-year period, a series of practical tests and inspection campaigns was carried out at laboratory scale, with a 3 km rail stretch and the average travel speed of 6 km/h. The objectives are to verify the practical effectiveness of the solutions in terms of vibration attenuation and performance reliability, on the basis of the balance between the induced level of complexity and the required reduction of vibration levels.

The work derives from the application of the new vibration criteria to transportation systems, and provides Vibration Quality Objectives which can be consistently used for the preliminary dimensioning of a broad range of vibrational tasks within a wide range of transportation applications. From the design action spectrum, the design vibration acceleration values can be directly deduced, allowing the required attenuation to be calculated and critically evaluated against the maximum path velocities.” [1]. Vibration control significantly contributes to increasing comfort and productivity: large efforts are now devoted by both research and industrial communities in order to develop effective and reliable systems. Future-oriented activities start from modeling and simulation to design dedicated solutions and provide a better understanding of the overall phenomena; advanced sensing and data analysis are implemented to maximize the amount of collected information and make available vibration data in real time; lastmentored control systems are then integrated to compensate the residual vibration and improve transportation quality [2].

For an active mounting system, the effectiveness of a vibration attenuator has also been checked by simulations and feasibility experiments [6]. The device uses a piezoelectric stack actuator in a chassis with a 3-path configuration –– two passive paths and one active path –– to attenuate the vibrations caused by excitation of an electric motor. The inspiration source was sinusoidal and modulated middle frequency band. Mathematical model followed the lumped-parameter source-path-receiver approach. Control allocation method was designed based on Normalized Least Mean Square (NLMS) and multi-NLMS. Experimental results verified the effect of the developed active mount for reducing vibrations, showing its potential in NVH performance improvement for EVs.

Testing Methodologies

The performance comparisons listed in all those papers highlight the need for extensive real life validation of vibration control approaches within the framework of smart transportation systems. Relying on well known theory and methodology, experimental demonstrations are required to verify theoretical predictions and simulation results [6]. Car models with multiple degrees of freedom (DoFs) connected with their aeroelastic responses, having road inputs, aerodynamic forces and suspension have been used to demonstrate how electrified active aeroelastic surfaces can be employed for trade-off in ride comfort and handling qualities. The validations put the emphasis on experimental test-benches such as the Vehicle Aeroacoustics and Road Noise Facility at German Aerospace Center (DLR) and the Road Load Simulator at Technical University of Munich, employing specific measurement hardware and control system simulation design with Simulink-Stateflow [7].

Regarding the latter, Takagi-Sugeno, or at least fuzzy model directly associated with it, is embraced as a formulation that can approximate complex and nonlinear systems dynamics given no system description exists. In general, the search for model forms as these can be based on a large set of experimental tests which records the dynamics of the complex system. There is a need for method development in this modeling environment to eliminate the time-consuming trial-and-error process for applications such as the Coil-on-Tube adaptive mount. The high-frequency phenomena are considered on the basis of a 6-DOF mass-spring-damper model with nonlinearities. Validation is to mount the adaptive types with the regular one, in order to experimentally simulate the high vibration event and for control potential demonstration purpose. This method generalizes to give a vibration suppression strategy for arbitrary systems.

**Case Studies in Real-World Applications**

Innovative vibration control designs have successfully transitioned from research to real-world experimental validation. Investigations of traffic-induced vibration in bridge structures and the application of vibration control in high-speed railway bridges represent distinct areas that have been extensively researched and cross-examined through a series of experimental studies and field observations [1] [3].

Vibration caused by traffic in bridge structures has been analysed by the attention to find optimal control designs with low supply of external power and dynamic loading immune. Semi-active control has been identified the most suitable system for avoiding traffic-induced damage without major structural intervention. This method combines performance with energy use; it is a suitable solution for integration environmentally friendly devices into existing infrastuctures.

High-speed railway bridges have also received significant attention by the more and more severe safety and comfort requirements for modern transportation. Several experimental works have confirmed the effectiveness of structural control systems specifically developed to mitigate train-induced vibration. Supportive field monitoring tests on twp-span articulated continuous prestressed cconcrete brdge 12 reiterates the engineering significance of such controls. The experimental realization of a deployable vibration control system for light truss type structures has also proven the possibility of simultaneous function of mobility and vibration attenuation, presenting its potential in broad applications [2].

Smart systems integrate myriad sensors distributed throughout their operational environment, facilitating data collection that informs on current vehicle conditions and enabling improvements in safety, economy, and ride comfort in real time. The sensor data further supports adaptive vehicle state feedback vibration control and the future deployment of autonomous vehicles. The need to enhance driving safety, economy, and comfort thus lies at the core of the smart vehicle concept. The experimental results presented confirm the efficacy of the approach [1] [2].

Smart materials and sensors have been extensively employed in vibration control, structural health monitoring, energy harvesting and shape morphing [6]. aimed to develop an active engine-mount system for the motion control of a plate-like structure made by a piezoelectric stack actuator. Simulation and experiments were conducted to verify the vibration attenuation effect. To verify the attenuation, a passive and an active path plate structures were simulated. The mathematical model with source-path-receiver structure was suggested, and the NLMS algorithm and the multi-NLMS were used for motion control. The proposed system was verified on experimental objects. Noted that the electric motor in hybrid/electric vehicles normally causes mid‐frequency vibrations and noise, which people feel unpleasant. Active vibration isolation is provided by smart structures, in the form of engine-mounting systems. Other adaptive control strategies, such as FX-LMS, sliding mode control and notch filters have been investigated. Some isolation has also been observed with MRAC- and sliding mode-controlled electromagnetic engine mounts.

The potential of applications is broadened by using portable and moveable vibration control units in addition to dedicated systems. Ensuring consistent vibration control performance across the drift time is difficult; certain locations are better than dedicated systems. [2] proposed a stand-alone deployable vibration control system, with the inexpensive components (system-on-chip microcontroller; electro-mechanical shaker) and the mobile platform (unmanned ground vehicle, UGV). The system becomes deployable and mobile, in that one can change the position of supervisors through time to improve performance when device placement is done after the controller designing. System identification is incorporated by means of the combined force generation resulting from the UGV and shaker. Even if the dynamics were also approximated in linear terms but not in a global (i.e., globally accurate) reciprocal mode, nonlinear models could be useful to attain higher precision and better mechanical systems design. The embedding exhibits deployability and autonimity with scarce ad hoc methodical extensions on top of off-the-shelf technology.

Vibration is a key indicator of the state of machines or structures. Condition monitoring aims at detecting abnormalities through vibration measurement. Vibration monitoring focuses on real-time vibration analysis and feedback control. The spread of the Internet of Things (IoT) enables ordinary users to access smart sensing devices, transmitting sensor data to servers via short-range wireless systems. High-performance motion sensors embedded in smartphones, tablets, and wearables can be applied to daily vibration monitoring. Automatic labeling of vibration data is important for unsupervised learning in smart transportation systems [8]. Some standard datasets intended for vibration analysis train modeling techniques to extract meaningful features from raw signals. The Politecnico di Torino Rolling Bearing Rig comprises four test bearings on a shaft driven up to 6000 rpm, with varying applied radial load and fault conditions. Accelerometers acquire data alongside temperature measurements on each bearing to measure the effect of faults on machine operation [9]. The rig presents in excess of 350 runs under various working conditions, with an extensive number of samples, from healthy to faults of various kinds and severity levels.

The deployment of an Unmanned Ground Vehicle (UGV) provides a permanently active and deployable vibration control system. The vehicle’s continuous mobility allows relocation of a vibration monitoring system over long time intervals, enabling both short-term measurements at multiple points and long-term measurements at critical or hardly accessible positions. Combining the mobility of the UGV with the force generation of an Electromagnetic Dynamic absorber (EMD) allows collection of input–output data for system identification purposes. Modeling the prototype device with a linear system approximates the inherently non-linear UGV dynamics. Although model errors were addressed with a robust controller, fitting nonlinear models for the UGV dynamics and implementing corresponding control algorithms remains a valuable line of investigation [2].

**CONCLUSION**

Smart transportation systems and the importance of vibration control are discussed in Section 2. To understand vibration basics and control approach used later in the paper, a brief review of these systems can be found. Next, the fundamentals of vibration are introduced that relate to the types which are critical for smart transportation systems. An inventory of active and passive control desks is given, which overcomes these works, equally providing emphasis to the theoretical aspects as well as the practical problems. The modelling and simulation approaches are then introduced in terms of mathematical formulations, and computational algorithms required to predict optimal control system for vibration suppression. The next step is experimental validation, including test references and real-world cases that demonstrate practically how the models and the control methodologies proposed work in this practice. The paper then discusses an integration of smart transportation technologies with vibration control. It considers sensors, data analytics and feedback systems that could enable in-situ monitoring and active response. These results contribute to the knowledge of vibration suppression and its use in smart transportation. It is proof positive, both of current successes and of potential.

**REFERENCES**

1. He, Y., Zhang, Y., Yao, Y., He, Y., & Sheng, X. (2023). Review on the prediction and control of structural vibration and noise in buildings caused by rail transit. *Buildings*, *13*(9), 2310. <https://doi.org/10.3390/buildings13092310>
2. Lee, J. W., Gunter, G., Ramadan, R., Almatrudi, S., Arnold, P., Aquino, J., ... & Seibold, B. (2021, May). Integrated framework of vehicle dynamics, instabilities, energy models, and sparse flow smoothing controllers. In *Proceedings of the Workshop on Data-Driven and Intelligent Cyber-Physical Systems* (pp. 41-47). <https://doi.org/10.1145/3459609.3460530>.
3. Rustamova, N. R. (2025, July). The role of vitagenic technologies in revolutionizing machine design and functionality. In *AIP Conference Proceedings* (Vol. 3304, No. 1, p. 030095). AIP Publishing LLC.  <https://doi.org/10.1063/5.0269690>
4. Xie, W., & Hua, Y. (2024). Structural Vibration Comfort: A Review of Recent Developments. *Buildings*, *14*(6), 1592. <https://doi.org/10.3390/buildings14061592>
5. Nodira Rustamova, Dildora Choriyeva, Marguba Abdurazokova, Sherzod Korabayev, Dilrabo Elmuratova, and Baxora Xamidullayevna Narzullayeva. (2025). Computational screening of photonic crystals using AI-driven methods, *Proc. SPIE 14014, Advanced Materials for Optics and Photonics: Chemistry and Engineering Perspectives (AMOP 2025), 1401410*; <https://doi.org/10.1117/12.3094117>
6. Li, Y., Sun, Z., Huang, M., Sun, L., Liu, H., & Lee, C. (2024). Self‐Sustained Artificial Internet of Things Based on Vibration Energy Harvesting Technology: Toward the Future Eco‐Society. *Advanced Energy and Sustainability Research*, *5*(11), 2400116. <https://doi.org/10.1002/aesr.202400116>.
7. Nodira Rustamova, Mamura Khakimova, Maftuna Islamova, Gulshad Yuldasheva, Shaymardon Norov, and Bekzod Islamov. (2025). Autonomous AI pipelines for high-throughput optical material screening", *Proc. SPIE 14014, Advanced Materials for Optics and Photonics: Chemistry and Engineering Perspectives (AMOP 2025), 1401411*; <https://doi.org/10.1117/12.3094132>
8. Qi, L., Pan, H., Pan, Y., Luo, D., Yan, J., & Zhang, Z. (2022). A review of vibration energy harvesting in rail transportation field. *Iscience*, *25*(3). <https://doi.org/10.1016/j.isci.2022.103849>
9. Rustamov, K. J., & Rustamova, N. R. (2025). Advanced hydraulic drive systems in multi-purpose machinery: Enhancing efficiency and performance in modern engineering. AIP Conference Proceedings, 3304, 030093. <https://doi.org/10.1063/5.0269688>
10. Ma, L., Xu, S., Wang, Z., Jia, L., Qin, Y., Li, X., ... & Chen, S. (2025). Energy self-contained freight train monitoring system with cooperative wind and vibration energy harvesting. *Energy*, 137418. <https://doi.org/10.1016/j.energy.2025.137418>
11. Rustamova, N. R., & Rustamov, K. J. (2025, July). Vitagen information and hydraulic drive systems in multi-purpose machinery: Enhancing performance and innovation. In *AIP Conference Proceedings* (Vol. 3304, No. 1, p. 030097). AIP Publishing LLC. <https://doi.org/10.1063/5.0269692>
12. Sharibaev, N., et al. (2024). A new method for digital processing cardio signals using the wavelet function. BIO Web of Conferences, 130, 04008. <https://doi.org/10.1051/bioconf/202413004008>
13. De Fazio, R., De Giorgi, M., Cafagna, D., Del-Valle-Soto, C., & Visconti, P. (2023). Energy harvesting technologies and devices from vehicular transit and natural sources on roads for a sustainable transport: state-of-the-art analysis and commercial solutions. *Energies*, *16*(7), 3016. <https://doi.org/10.3390/en16073016>
14. Hong, D., Qiu, Y., & Kim, B. (2023). Vibration characteristics of an active mounting system for motion control of a plate-like structure in future mobilities. *Scientific Reports*, *13*(1), 16278. <https://doi.org/10.1038/s41598-023-43419-w>
15. Al-Bakri, A. Y., & Sazid, M. (2021). Application of artificial neural network (ANN) for prediction and optimization of blast-induced impacts. *Mining*, *1*(3), 315-334. <https://doi.org/10.3390/mining1030020>