

BOOK OF ABSTRACTS

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ABOUT THE CONFERENCE

The XI International Conference on Computational Methods in Engineering Science (CMES'26) continues the tradition of bringing together researchers and practitioners to exchange knowledge and discuss advances in computational methods and their applications in engineering. The eleventh edition will be held on November 18–20, 2026, for the second time in Cedzyna near Kielce, Poland.

The conference is jointly organized by the Lublin University of Technology (Faculty of Mechanical Engineering, Faculty of Electrical Engineering and Computer Science, Faculty of Management, and Faculty of Environmental Engineering), the Polish Air Force University (Faculty of Aviation), Polish Society for the Promotion of Knowledge and Polish Society of Engineering Sciences.

Conference Background and Development

Since its establishment in 2016, CMES has developed into a recognized annual scientific event, bringing together researchers from academic institutions, research centers, and industry in Poland and abroad. Over the years, the conference has expanded its thematic scope, strengthened its international participation, and established a platform for interdisciplinary scientific exchange.

Previous editions have been organized in various locations across Poland, including Lublin, Kazimierz Dolny, Zamość, Puławy, Sandomierz, and Cedzyna. The conference has maintained its continuity despite the challenges posed by the COVID-19 pandemic, during which the 2020 edition was conducted entirely online (Fig.1). Following the successful tenth anniversary edition in 2025, CMES'26 marks the beginning of the conference's second decade. Building on the achievements of previous editions, the conference continues to promote scientific excellence, international cooperation, and the practical application of innovative computational approaches to engineering challenges.

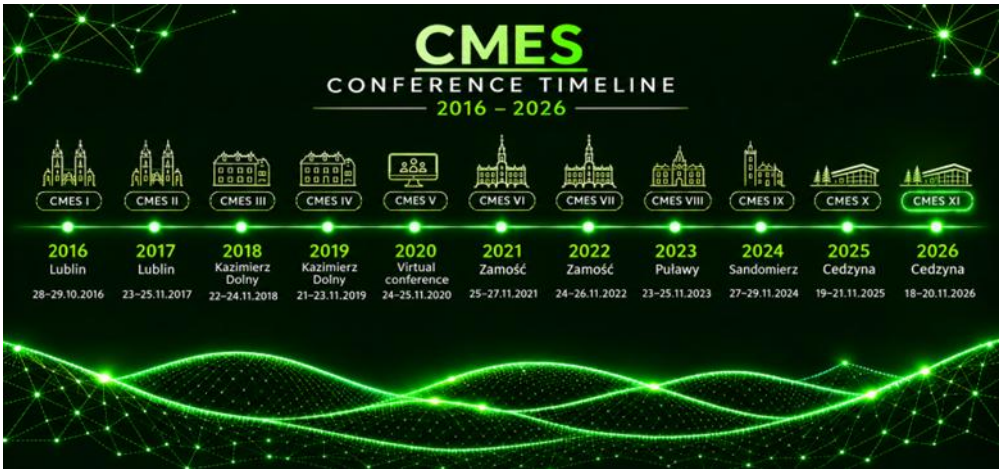

Figure 1. Timeline of CMES conference locations

Scientific Scope and Objectives

CMES'26 conference is expected to bring together approximately 137 participants, including researchers, keynote speakers, and industry representatives. The conference covers a broad spectrum of engineering disciplines, with particular emphasis on the development, implementation, and validation of computational and numerical methods. The main thematic areas include:

- analysis and modeling of engineering processes,
- computer-aided design, simulation, and optimization,
- artificial and computational intelligence,
- Computational Fluid Dynamics (CFD),
- Finite Element Method (FEM) and related numerical approaches,
- experimental and computational methods in materials and structural research,
- production engineering and quality control,
- technology management in energy and sustainable processes.

The scientific program will feature keynote lectures, thematic sessions, and presentations addressing both fundamental research and practical engineering applications. Particular attention will be given to the integration of numerical simulations, experimental investigations, data-driven approaches, and advanced computational tools in solving complex engineering problems.

The interdisciplinary character of CMES encourages the exchange of expertise across different research fields and supports the establishment of new scientific partnerships. By connecting academic research with industrial practice, the conference contributes to the development of innovative engineering solutions and promotes the transfer of scientific knowledge into practical applications.

Scientific Publications and Knowledge Dissemination

One of the principal objectives of CMES is to disseminate recent scientific achievements and promote high-quality research in computational engineering science. The conference provides researchers with an opportunity to present their findings, discuss methodological developments, and receive valuable feedback from experts representing different engineering disciplines. Selected papers presented at CMES'26, subject to a positive peer-review process and the editorial requirements of the respective journals, may be considered for publication in the following scientific journals:

- Advances in Science and Technology Research Journal
- Acta Mechanica et Automatica
- Archives of Electrical Engineering
- Applied Computer Science
- Journal of Ecological Engineering
- Management Systems in Production Engineering
- Advances in Materials Science

Future Perspectives

Entering its second decade, CMES continues to strengthen its position as an international forum for scientific discussion and interdisciplinary collaboration in engineering science. The conference aims to further develop cooperation between universities, research institutions, and industrial partners, while encouraging the participation of both established scientists and early-career researchers.

An important direction for future editions is the increasing integration of advanced computational methods, artificial intelligence, numerical modeling, and experimental validation in engineering research. Particular emphasis will also be placed on the development of solutions addressing contemporary technological, industrial, and environmental challenges. CMES'26 represents another step in the continued development of the conference, reinforcing its commitment to scientific excellence, knowledge exchange, and international scientific collaboration.

More information about CMES'26 and previous editions is available on the official website:

www.cmes.pl

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CMES'26 Organizing Committee structure and team members
from the left: J. Pizoń, W. Cel, J. Kujawska, Z. Czyż,
K. Falkowicz, M. Szala, M. Kulisz, M. Badurowicz

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ASSOCIATED EVENTS

RECONSTRUCTION AND AERODYNAMIC INVESTIGATION OF THE LUBLIN R-XIIID AIRCRAFT – CURRENT PROGRESS AND PROJECT DEVELOPMENT

This year's edition of CMES'26 will feature a special session entitled "Application of Numerical Methods in the Reconstruction of the Lublin R-XIIID Aircraft – Current Progress and Project Development," dedicated to presenting the current progress of the project and the application of numerical and experimental methods in the aircraft reconstruction process.

CMES'26 KEYNOTE SPEAKERS



DATA AND MODELS USED IN ENGINEERING APPLICATIONS

Hasilova Kamila, PhD
Department of Quantitative Methods,
University of Defence,
Brno, Czech Republic

ABSTRACT

Data and models present one of the first steps in statistical modelling, which is then followed by applications in decision-making or maintenance processes. With a focus on the non-parametric methods for the assessment, modelling and simulation of data in the fields of military and civil protection, we present models that are used to solve critical infrastructure and systems of physical protection tasks. Some problems require new perspectives to solve, including the type of data involved. Therefore, we provide an introduction to the so-called circular data and functional data, which have different characteristics. The overview of the models and data types demonstrates the wide range of possibilities in statistical modelling. Statistical methods are viewed as a tool that makes it possible to extract meaningful information from available data drawn from various areas of the field. This information can then be used for modelling and simulating the processes under study.

SPEAKER BIOGRAPHY

Kamila Hasilová works at the University of Defence in Brno, Czech Republic. She received her Ph.D. degree in Probability, Statistics and Mathematical Modelling from Masaryk University in 2012, and the habilitation degree in the field of Military and Civil Protection in 2020. She specialises in the statistical methods and mathematical modelling in defence and protection areas, focusing on data analysis, non-parametric statistical methods and statistical modelling. She has presented her results in peer-reviewed journal, about 70 papers, and at international conferences, about 40 oral and poster presentations.

MULTIPHYSICS ANALYSIS OF ELECTROMAGNETIC-THERMAL COUPLING IN CST STUDIO SUITE AND CO-SIMULATION WITH ABAQUS





Rafał M. Wojciechowski,
DSc, Technia, Poland

Dominik Gawle, MEng
SIMULIA Sales Representative
at Dassault Systèmes

ABSTRACT

The continuous push for higher power density and miniaturization in modern electromechanical systems-ranging from high-frequency electronics to high-power electrical machines-requires a rigorous approach to Multiphysics modelling. Thermal management is considered a critical bottleneck in the design process, as electromagnetic losses directly impact temperature distribution, which in turn alters material properties and structural integrity. In this presentation, the advanced capabilities of **CST Studio Suite** in simulating coupled electromagnetic (EM) and thermal phenomena are analysed, alongside its integration with **Abaqus FEA** for comprehensive structural analysis.

In the first part of the study, the **EM-Thermal coupling** within the CST Studio Suite environment is examined. By utilizing integrated Multiphysics Solvers, bi-directional simulations are performed, where electromagnetic losses (such as surface losses, volumetric losses, or eddy currents) are treated as heat sources for the thermal solver. The workflow accounts for temperature-dependent material properties, ensuring that high fidelity is maintained in predicting the thermal behavior of components under various operating conditions.

The second part of the work highlights the synergy between **CST Studio Suite and Abaqus** within the Dassault Systèmes SIMULIA portfolio. While CST is recognized for its excellence in EM and thermal analysis, certain applications-such as induction heating,

power electronics cooling, or transformer design-demand a more profound investigation into mechanical effects. The **SIMULIA Co-Simulation Engine** is presented as a solution that facilitates the transfer of temperature fields and electromagnetic forces from CST to Abaqus. Through this coupling, several key analyses are enabled:

- Precise calculation of thermal stresses induced by electromagnetic heating.
- Structural deformation analysis of components subject to high-intensity fields.
- Optimization of cooling systems through combined CFD and mechanical assessments.

It is demonstrated by the authors how this integrated Multiphysics workflow allows for the reduction of physical prototyping and minimizes the risk of over-design. By leveraging the unified power of CST and Abaqus, the gap between electromagnetic performance and mechanical reliability is bridged, ultimately accelerating the time-to-market for innovative products.

SPEAKER BIOGRAPHY

Assoc. Prof. Rafał M. Wojciechowski received the MSc degree in Electrical Engineering from the Poznan University of Technology in 2005, PhD and D.Sc. degrees in 2010 and 2017, respectively. His scientific interests are focused on numerical modeling and analysis of electrical machines and devices using the multi-stage approach of the finite elements method (FEM). Over 70 papers on electrical machines, electrical and electronic devices, and systems of wireless transmission power have been published by him. He is a co-author of 3 international patents and 9 patent applications. For 3 years, he has cooperated with Technia Poland as a Simulation expert in the EM field.

Dominik Gawle has been associated with the CAD/SIM/CAM/PDM software market for engineers for 20 years. Extensive knowledge of Dassault Systèmes solutions has been acquired by him through various technical and sales roles. He is a graduate of Cracow University of Technology in the field of Automation and Robotics, as well as a postgraduate of AGH University of Science and Technology in Project Management. Currently, he is responsible for leading projects and developing sales in the SIMULIA domain, supporting Dassault Systèmes clients and partners in Poland.



LIVING ON THE EDGE: EDGE AI FOR SPEED, PRIVACY, AND SELF-GOVERNANCE

Marcin Badurowicz, PhD, Eng.
Lublin University of Technology

ABSTRACT

Edge computing is an approach to data processing in which computation is moved closer to where data is generated, rather than relying exclusively on centralized infrastructure. This shift enables devices to process, analyze, or act on data locally, reducing the need to continuously transmit large amounts of data to remote servers. With the growing capabilities of embedded hardware and AI models, this approach also enables Edge AI, running machine learning and artificial intelligence algorithms directly on edge devices.

In this plenary lecture, it will be shown how edge processing is being applied to data processing in various applications, what challenges and limitations can be encountered, and why this approach is becoming increasingly interesting. The lecture will focus on two main pillars: the first is speed and latency, where edge processing and Edge AI can outperform traditional approaches by enabling fast, local decision-making, even when more accurate or computationally powerful solutions are available in the cloud; the second is privacy and self-governance: in today's world, transferring and sharing data can introduce significant business, regulatory, and legal risks.

The lecture will also highlight the trade-offs involved in moving computation to the edge, including limited computational and energy resources, model complexity, reliability, scalability, and the challenges of deploying and maintaining distributed AI systems.

SPEAKER BIOGRAPHY

Marcin Badurowicz works at the Lublin University of Technology in Poland. He received his PhD in computer science in 2019 from the Polish-Japanese Academy of Information Technology for his work on pothole detection in road transport with the usage of mobile devices and on-device processing. He is the author or co-author of more than 30 papers, and his work concentrates on various aspects of anomaly detection, language processing, and XR technologies.



COMPUTATIONAL INTELLIGENCE FOR MANAGING MODERN PRODUCTION SYSTEMS

Jakub Pizoń, PhD, Eng.
Lublin University of Technology

ABSTRACT

The aim of this plenary lecture is to show how computational intelligence is currently applied to support the management of modern production systems and to identify areas where these solutions can create practical value and new research opportunities. The lecture focuses on specific production processes, including planning and scheduling, quality control, maintenance, intralogistics and human–machine collaboration.
For each area, selected real-world examples will illustrate what operational problem is addressed, what data are used, which computational methods are applied and what decisions or activities they support. Particular attention will be given to artificial intelligence, predictive methods, digital twins and intelligent decision-support systems.
The lecture will also discuss practical implementation conditions, including data availability, integration with existing production systems, model reliability and organisational adoption. By linking computational methods with concrete production processes and managerial decisions, the presentation aims to provide participants with an application-oriented perspective and inspire further research into emerging uses of computational intelligence in manufacturing.

SPEAKER BIOGRAPHY

Experienced Business Solutions Architect, researcher and academic lecturer with over fourteen years of experience delivering business system solutions for enterprises and public institutions. Demonstrated history of successfully supporting public procurement processes and implementing advanced technologies. Skilled in business architecture, project management, data analysis and leading cross-functional teams, with a proven ability to deliver strategic solutions in complex environments.
Active in research and teaching in process management, artificial intelligence and modern information technologies for Industry 4.0 and 5.0. Leads R&D projects applying large language models (LLMs) in medical transcription and project management. Author of more than forty academic publications on integrating technology with business processes and a regular speaker at industry conferences.

Certified in project management (IPMA Level D, PSM I, AgilePM Foundation), business analysis (ECBA by IIBA) and software estimation (COSMIC Foundation). Holds a PhD in Mechanical Engineering focused on business and technology integration. Combines the perspectives of an IT practitioner, R&D innovator and educator to address the real-world challenges organisations face in the era of digital transformation.



EVALUATION OF THE EFFECTIVENESS OF RADAR DRONE DETECTION: THE APPLICATION OF COMPUTER SIMULATIONS

Przemysław Turos
Symkom Sp. z o.o.

ABSTRACT

The evolving threat landscape on NATO's eastern flank highlights the critical necessity of adapting air defense capabilities to counter Unmanned Aerial Vehicles (UAVs). Small and medium-sized drones present significant detection challenges due to reduced radar cross-sections (RCS), complex material compositions, low-altitude flight profiles, and rapidly evolving operational tactics. The presentation introduces a multidisciplinary methodology utilizing advanced engineering computer simulations to evaluate and optimize radar detection performance against low-observable UAV targets without relying solely on costly field testing.

The proposed framework integrates a multi-stage workflow: first, detailed 3D electromagnetic target modeling, high-frequency RCS prediction via Shooting and Bouncing Ray method, mission-level operational simulations incorporating topography, atmospheric attenuation, dynamic flight trajectories, and electronic warfare (EW) conditions and finally, flight-test data analysis for radar calibration.

The results demonstrate that mission-level digital simulations effectively identify coverage gaps, quantify detection probabilities, evaluate jamming resilience, and enable optimized radar placement and signal parameters. This integrated virtual testing approach serves as a cost-effective, scalable decision-support tool for modern air defense design, threat forecasting, and tactical doctrine development against evolving unmanned aerial systems.

SPEAKER BIOGRAPHY

Przemysław Turos, graduated from Warsaw University, the Geography and Regional Studies Department. He completed postgraduate studies in Aviation Management at the National Defense Academy in Warsaw. He has wide, long term experience in Remote

Sensing and Geographical Information Systems applications, data mining, processing and analysis, as well as in the field of Digital Mission Engineering.
Previously held the position of the Chief Operating Officer in GEOSYSTEMS Polska. Since 2016 runs Topologic Consulting, specialized in advisory and implementation in the field of aerial and satellite monitoring systems and data fusion in various domains. In 2019 the company become the Polish Agent of Analytical Graphics Inc., producer of DME solutions, currently part of Ansys Inc., a producer of engineering simulation software. Closely cooperates with Symkom Sp. z o.o. an Ansys Channel Partner in Poland as sub-distributor.

ABSTRACTS

ANALYSIS OF ENGINEERING PROCESSES

EVALUATING HYDRODYNAMIC CAVITATION FOR INCREASE OF BIODEGRADABILITY OF HERBAL WASTE: A MULTI-CRITERIA APPROACH

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Abstract: This paper is focused on the issue of selecting the operational parameters of the hydrodynamic cavitation (HC) that provide a maximum increase in the biodegradability of herbal waste with possibly low energy demand. To achieve this goal, the Multi-criteria Determination of Recommended Variants (MCDRV) method was applied, which allows for selecting the most advantageous HC conditions taking into account a variety of, sometimes conflicting, indicators of the process evaluation. The typical inference methods proved useless in determining which of the runs could be recommended due to the complexity of the experimental data, as well as the plethora of evaluation criteria expressed in different units, as the best solution. Using MCDRV, a multi-criteria analysis was performed for 21 detailed variants in order to select the optimal HC conditions that fulfill prior assumptions of the study. For searching for the best variant or variants of HC, the following criteria were defined: BOD/COD, SCOD/COD, and SCOD, which were maximized, and the others, i.e., COD, BOD, phenols concentration, and energy consumption, which were minimized. Both the seven-criteria and five-criteria evaluations of 21 variants obtained in the experiment showed that when adopting the same and different values of the importance of individual criteria, some variants are never selected as a compromise. The variant that was repeatedly selected as a compromise solution, independent of the values of the weight of individual criteria and the number of criteria, was the variant for which the HC time was 10 minutes and the cavitation inlet pressure was 3.5 bar. The multi-criteria assessment indicated that such operational conditions should be recommended for the efficient HC process of herbal waste.

Keywords: hydrodynamic cavitation, herbal waste, biodegradability, multi-criteria analysis

ASSESSMENT OF THE CARBON FOOTPRINT OF BIOCHAR PRODUCTION FROM SEWAGE SLUDGE USING CALCULATION METHODS

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Abstract: Producing biochar from sewage sludge is one option for sludge management; however, assessing the climate-related viability of this solution requires accounting for emissions associated with feedstock preparation and processing. This study aims to present a methodology for calculating the carbon footprint of biochar production and to compare variants that differ in pyrolysis temperature and energy supply methods. The proposed methodology is based on a material and energy balance and the use of greenhouse gas emission factors. The functional unit adopted is the processing of 1 Mg of sewage sludge dry matter, with results also calculated per 1 kg of dry biochar. The system boundaries encompass the transport of dewatered sludge, drying, feedstock preparation, pyrolysis, product cooling, and the management of process residues. The model accounts for electricity and heat consumption, inert gas usage, and direct emissions. The analysis compares pyrolysis temperatures of 400, 500, and 600°C, factoring in variable biochar yields and energy requirements. A sensitivity analysis regarding initial sludge moisture content, transport distance, and the electricity emission factor complements the study. Internal energy recovery is accounted for by reducing the demand for external energy. Potential carbon sequestration in the biochar is considered separately, depending on carbon stability and the product's intended application. The proposed approach enables the identification of the stages that contribute most significantly to emissions and the assessment of the impact of process parameters on the carbon footprint. It can serve as a tool to support the selection of biochar production conditions and the evaluation of sewage sludge management options.

Keywords: carbon footprint, biochar, sewage sludge, pyrolysis, material and energy balance, sensitivity analysis

VERIFICATION OF FOREARM GRID GENERATION METHODS FOR EMG ELECTRODE PLACEMENT DURING WHEELCHAIR PROPULSION STUDIES

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Abstract: The lack of a standardized and reproducible method for placing surface electromyography (sEMG) electrodes on the forearm leads to increased variability and limited comparability of results in biomechanical analyses. The aim of this study was to evaluate methods for generating grids on the forearm for sEMG studies during wheelchair propulsion. The analysis considered three grid variants based on different assumptions: a grid with a fixed linear spacing, a grid defined based on anthropometric points, and a grid drawn using a forearm template. A multi-criteria evaluation of the methods under consideration and experimental sEMG studies was conducted. The analysis took into account criteria such as participant discomfort, time required to prepare the grid, alignment of grid fields with electrode size, ease of use, versatility of the method, EMG signal amplitude, and degree of muscle coverage. The results of the multi-criteria evaluation made it possible to identify the solution with the highest efficiency based on the established criteria. The most advantageous method turned out to be generating a mesh according to the principle of constant linear spacing. This method received the highest final score, demonstrating a particular advantage in key criteria such as muscle coverage and versatility. The result obtained was 16.84% higher compared to the second-best solution. The analysis indicates that the placement of measurement electrodes significantly affects the quality of the recorded sEMG signal. The results underscore the need to develop a methodology that enables the repeatable positioning of electrodes, particularly in the context of long-term biomechanical studies related to wheelchair propulsion.

Keywords: surface grid, EMG grid, electrodes location, electrodes arrangement, arm grid generation, grid generation methods

AI-BASED OPERATOR BEHAVIOR PREDICTION ALGORITHM FOR HUMAN-ROBOT COOPERATION

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Abstract: The use of industrial robots are increasingly being utilized in processes carried out in cooperation with humans. A wide range of studies have focused on advancing novel approaches aimed at enhancing the level of interaction. However, the existing solutions typically rely on the integration of multiple hardware components, with the consequent high costs and complexity. In response to the outlined problems, this paper presents an AI-based algorithm designed to anticipate operator actions within a human–industrial robot collaborative framework. The developed algorithm has been verified based on experimental data, with the obtained outcomes confirming the validity and practical applicability of the developed method. Utilized the research workstation for operator behavior analysis, implemented the algorithm by means of the Python language, and, through simulation of the robot's operation within a computational simulation framework, the approach was successfully verified. Based on the conducted tests for each operator, a decrease in the execution time of the pick and place task was observed. The achieved reduction varied between 4% and 12.4%.

Keywords: prediction, artificial intelligence, industrial robot, efficiency

MATHEMATICAL MODELING AND OPTIMIZATION OF DRY FRACTIONATION OF WHEAT FLOUR IN A PNEUMATIC SCREW CLASSIFIER

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Abstract: Pneumatic centrifugal classification is a sustainable dry fractionation technology for cereal flours, avoiding water use and preserving native functionality. This study provides a mathematical analysis of how the adjustable slot opening degree (φ) influences efficiency, yield distribution, purity, and selectivity in wheat flour processing. A key innovation is a two-phase gas-solid flow model incorporating the material loading coefficient (μ), validated against experimental data at 500 kg/h. Based on force mechanics, the aerodynamic drag force follows a quadratic dependence on air velocity ($Fd \sim V^2$). Critical velocity criteria derived from momentum balance define threshold conditions for particle separation: lighter protein-rich particles entrain into the light fraction, while denser starch-rich particles migrate outward. Engineering calculations show that the optimal operating window occurs at φ between 0.30 and 0.40. Within this range, protein purity in the light fraction reaches 91–93%, while starch purity in the heavy fraction attains approximately 96%. The intermediate middlings fraction is minimized to 80–100 kg/h. The selectivity coefficient peaks at Sint = 3.94 at φ = 0.30, confirming strong preferential separation. Additional validation criteria are satisfied within the optimal range: the residence time condition ($t_{res} \geq t_{need}$) ensures sufficient differential migration, while the heavy particle retention criterion ($v_{s*} < V_{st}$) confirms that starch-rich particles are effectively directed to the heavy fraction. Taken together, these findings establish a quantitative predictive framework for rational design and optimization of pneumatic centrifugal classifiers, offering engineers and food processors clear operating guidelines to maximize protein and starch purity while minimizing mixed intermediate fractions. This work advances energy-efficient, water-free fractionation technologies for plant-based ingredients.

Keywords: air classification, dry fractionation, pneumatic classification, protein–starch separation, selectivity coefficient, two-phase flow, wheat flour fractionation

WIND TUNNEL AERODYNAMIC EXPERIMENTAL RESULTS OF THE LUBLIN R-XIIID AIRCRAFT MODEL

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Abstract: This paper presents the methodology and results of wind tunnel aerodynamic testing conducted on a scaled model of the Lublin R-XIIID aircraft. The experimental campaign was carried out in the closed-circuit wind tunnel at the Lublin University of Technology. The primary objective was to determine the complete aerodynamic characteristics of the airframe and to evaluate the structural configuration regarding aerodynamic performance and static stability. The 1:14 scale model was manufactured using 3D printing (PLA) based on CAD geometry previously validated through computational fluid dynamics (CFD). Due to test section dimensions and 3D printing build volume constraints, the model was constructed from 20 modular, glueless elements reinforced with carbon fiber, brass, and threaded steel rods. Aerodynamic forces and moments were measured using an FMT 625 six-component internal balance coupled with a QuantumX MX440B data acquisition system at flow velocities up to 50 m/s. The experimental program comprised seven test series encompassing 1,779 measurement points across angles of attack ranging from -22° to +22°, sideslip angles, and various control surface deflections (elevator, rudder, ailerons, and horizontal stabilizer). Measured loads were converted into dimensionless aerodynamic coefficients (Cx, Cy, Cz, Cm, Cn) referenced to the center of gravity located at 1/4 of the mean aerodynamic chord. The analysis confirmed a linear longitudinal stability behavior with a static margin of approximately 0.25 within the usable angle-of-attack range, verifying the aerodynamic integrity of the aircraft design and the effectiveness of its control surfaces.

Keywords: blin R-XIIID, wind tunnel testing, aerodynamic characteristics, 3D printing, aerodynamic balance

A FORMAL GRAPH MODEL OF AN EMBODIED DATA PUMP FOR IOT–MIXED REALITY INTEGRATION

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Abstract: Distributed industrial applications increasingly combine heterogeneous data sources with operator-facing mixed-reality interfaces, yet their communication and control relationships are difficult to specify consistently. This paper proposes a formal graph-based model of an Embodied Data Pump (EDP) that integrates database access and IoT messaging based on MQTT, Kafka, and WebSocket communication with a HoloLens 2 environment. The architecture is represented as a directed labeled graph G = (V, E, l). Its vertices capture data clients, protocol connectors, the EDP, the Tomoverse broker and management services, the HoloLens device, and scene-level visualization and interaction components. Edges encode message-flow and control dependencies, while the labeling function records the communication protocol, endpoint pair, and directionality. The formalization links an abstract extract–transform–load process with computation, communication, and spatial interaction in a single representation. Its feasibility is illustrated by mapping the model onto a prototype in which sensor and broker data are exposed through mixed-reality panels, indicators, connectors, and configurable pump plug-ins. The proposed model provides a traceable basis for comparing architecture with implementation and for designing subsequent experiments on throughput, reliability, task comprehension, and system configuration time. Rather than reporting completed performance validation, the work establishes the formal and prototypical foundation required to evaluate embodied data interfaces in industrial IoT and digital-twin environments.

Keywords: embodied data pump, Internet of Things, mixed reality, directed graph model, data integration, HoloLens 2, MQTT, Kafka

EXPERIMENTAL INVESTIGATION OF NONLINEAR DYNAMICS AND PIEZOELECTRIC RESPONSE OF AN AIRFLOW-INDUCED VIBRATING BEAM

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Abstract: This study presents an experimental investigation of the dynamic response of a cantilever beam subjected to airflow excitation and its associated piezoelectric response. The research focuses on identifying changes in the vibration characteristics of the beam with increasing airflow velocity and determining how these changes are reflected in the electrical signal generated by a piezoelectric patch attached to the structure. Experiments are conducted in an aerodynamic wind tunnel for airflow velocities. The mechanical response of the beam is measured using a laser Doppler vibrometer, while the voltage generated by the piezoelectric element is recorded simultaneously. The obtained signals are analyzed in both the time and frequency domains using statistical measures, root mean square values, and Fourier transform analysis. In addition, experimental bifurcation diagrams and phase-space representations are employed to investigate changes in the dynamical state of the system as a function of airflow velocity. The comparison of mechanical and electrical responses enables the assessment of the relationship between airflow-induced vibrations and piezoelectric energy conversion. The proposed approach provides an experimental framework for identifying changes in the nonlinear dynamic behavior of airflow-excited structures and evaluating their potential for vibration-based energy harvesting.

Keywords: piezoelectric element, beam, energy harvesting, bluff body, electrical signal

MATHEMATICAL MODELLING AND EXPERIMENTAL INVESTIGATION OF A BLDC-BASED ENERGY HARVESTER UNDER NONLINEAR MECHANICAL EXCITATION

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Abstract: This study investigates the dynamic behaviour and electrical response of a vibration energy harvesting system incorporating a brushless DC (BLDC) machine operating as a generator under nonlinear mechanical excitation. The objective is to determine how excitation parameters and electromechanical interactions affect the system response and the amount of electrical energy harvested. The research combines mathematical modelling, numerical simulations, and experimental investigation. The mathematical model describes the coupled mechanical and electrical dynamics, accounting for inertia, damping, nonlinear excitation, and the interaction between rotor motion and electromagnetic torque. Numerical simulations are used to examine the influence of excitation frequency and amplitude, as well as electrical loading, on rotor motion, induced voltage, and generated power. Particular attention is paid to identifying operating conditions that support effective energy conversion and assessing changes in the dynamic response across the investigated parameter range. Experimental measurements are performed under controlled mechanical excitation. Mechanical and electrical signals are recorded and analysed in the time and frequency domains using root mean square values, spectral analysis, and phase-space representations. Electrical power is evaluated to assess the relationship between the mechanical response and energy harvesting performance. Comparing numerical predictions with experimental measurements enables model validation and assessment of its ability to reproduce the behaviour of the physical system. The proposed approach provides a framework for understanding nonlinear electromechanical interactions and selecting excitation and loading parameters that improve the performance of BLDC-based vibration energy harvesters.

Keywords: vibration energy harvesting, nonlinear excitation, mathematical modelling, electromechanical coupling, experimental investigation

NUMERICAL AND EXPERIMENTAL INVESTIGATION OF THE DYNAMICS OF COUPLED ELASTIC BEAMS SUBJECTED TO MECHANICAL EXCITATION

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Abstract: This study investigates the dynamic response of a system of coupled elastic beams subjected to mechanical vibration excitation. The objective is to determine how excitation and coupling parameters affect the vibration characteristics of the system, with particular emphasis on resonance phenomena and interactions between individual components. The research includes mathematical modelling, numerical simulations, and experimental validation. The system model accounts for the inertial and elastic properties of the beams, damping, and coupling interactions. Numerical simulations are used to determine the system response under varying excitation frequencies and amplitudes, as well as coupling parameters. The experimental investigation involves measuring the vibrations of individual beams under controlled mechanical excitation. The acquired signals are analysed in the time and frequency domains using root mean square values, spectral analysis, and amplitude–frequency response curves. A comparison of vibration amplitudes and phase relationships enables the assessment of vibration synchronisation and the distribution of the dynamic response among the beams. Comparing simulation results with experimental measurements allows the agreement between the model and the behaviour of the physical system to be assessed and the model's range of applicability to be determined. The proposed approach aims to identify conditions leading to vibration amplification or suppression and to evaluate the potential for shaping the dynamic response by adjusting coupling parameters. The research provides a basis for designing multi-element elastic systems for vibration control and their potential application in mechanical vibration energy harvesting.

Keywords: elastic beams, mechanical coupling, forced vibrations, system dynamics

APPLICATION OF COMPUTER PROGRAMS IN TECHNOLOGY

SCALABILITY ANALYSIS AND PERFORMANCE EVALUATION OF WEBRTC SYSTEMS USING THE INFRASTRUCTURE AS CODE PARADIGM AND CONTAINERIZED TRAFFIC GENERATORS

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Abstract: The dynamic development of remote education and distributed work has driven the demand for reliable real-time communication platforms. Ensuring the stability of such systems under massive load is a standard engineering challenge, necessitating robust methodologies for scalability assessment and proactive cloud infrastructure monitoring. Despite substantial progress in WebRTC benchmarking, practical gaps remain in the context of high-concurrency educational deployments. To achieve rigorous experimental repeatability and eliminate the configuration drift common in traditional load testing, the research adopted an advanced evaluation framework based on declarative infrastructure provisioning (Infrastructure as Code). The target environment for this evaluation was the BigBlueButton (BBB) system (version 3.0.19), deployed on a high-capacity server (e.g., 64 vCPU, 315 GiB RAM) as part of a major educational project in Poland. The traffic generation environment consisted of a distributed cluster of Docker containers, ensuring full isolation and repeatability of test scenarios. End-user simulation (utilizing headless Chromium clients and standard video resolution profiles) was implemented using scripts based on the Playwright library, allowing for the emulation of realistic interactions with the WebRTC interface. Iterative load tests at a scale of up to 421 users demonstrated the high efficiency of the server cluster, which provided empirical evidence that backend compute resources do not constitute the exclusive limiting factor in massive-scale deployments. The analysis revealed that the critical limitation of the system is the performance of the client-moderator's browser, which loses functionality beyond the threshold of 250 active video streams despite significant server resource redundancy. Quantitative metrics confirmed this imbalance: at peak load, server CPU utilization

hovered between 12.1% and 16.2%, and RAM usage reached only 10 GiB out of 315 GiB, whereas external network traffic peaked at 374 Mb/s with a noticeable rise in TCP retransmissions and packet drops. The results confirm that the analyzed infrastructure is capable of stably supporting user groups that significantly exceed the initial design assumptions. The research suggests that for sessions exceeding 250 participants, engineering efforts should focus on client-side application optimization and local workstation resource management, rather than merely scaling server resources.

Keywords: distributed systems, Docker, load testing, real-time communication, Terraform, cloud resources, end-user simulation, automated testing methodology

SIMULATION STUDIES OF THE SPRAY WASHING PROCESS

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Abstract: Simulation studies of the spray washing process are an essential tool for analyzing and optimizing cleaning processes across various industries. In this study, a two-pronged approach was used to model the phenomena occurring when a liquid jet interacts with the surface being cleaned. The first stage involved the use of the DPM (Discrete Phase Model) method, which allows for the tracking of droplet trajectories in the spray stream, taking into account the transition to a liquid film model on the surface using the EWF (Eulerian Wall Film) concept. In the second approach, the SPH (Smoothed Particle Hydrodynamics) method was used, which enabled mesh-free flow modeling and a more accurate representation of phenomena related to jet deformation and droplet coalescence in the spray upon contact with the surface. Simulations were performed for various operating parameters of the spray system, such as operating pressure, nozzle angle, and nozzle-to-surface distance, allowing for an assessment of their impact on the cleaning process. In particular, the analysis focused on velocity distribution, liquid coverage intensity, and the dynamics of droplet-substrate interaction. The simulations conducted made it possible to compare the effectiveness of modeling key physical phenomena, such as spray distribution, liquid coverage, and the dynamics of droplet-substrate interaction. It was demonstrated that the DPM–EWF model provides computational efficiency while maintaining an accurate description of macroscopic phenomena, whereas the SPH method allows for a more detailed analysis of local hydrodynamic effects. The results obtained can serve as a basis for optimizing spray washing process parameters and for the further development of numerical models used in engineering practice.

Keywords: DPM, SPH, EWF, fluid flow, cleaning process, spray washing

LOW-COST MEASUREMENT OF LIGHT POLARISATION PLANE ROTATION USING DOUBLE TFBG SENSORS WITH POWER-BASED INTERROGATION

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Abstract: This article presents a new method for measuring the angle of rotation of the light polarisation plane (LPPR) using a dual-channel power-based approach with tilted Bragg gratings (TFBG) and Bragg gratings (FBG), and optical power measurement. Unlike previous solutions based on the analysis of the full transmission spectrum of the TFBG, the proposed method does not require the use of an optical spectrum analyzer. The measurement system consists of two optical paths containing TFBGs positioned at a 45° angle to each other, working in conjunction with FBGs acting as spectral filters. The optical power values recorded in both channels are used to determine the angle of rotation of the polarization plane based on previously determined calibration characteristics approximated by a Fourier series. An analysis was carried out of the effect of the relative positions of the TFBG and FBG spectra on the amplitude of power variations and the distortion of measurement characteristics. It was demonstrated that the appropriate selection of the FBG reflection band position relative to the selected TFBG cladding mode allows the amplitude of the measurement signal to be increased whilst maintaining low distortion of the characteristics. The effectiveness of the developed method was experimentally verified in the range of angles from 0° to 180°. For an independent test set, a mean absolute error of 0.27°, an RMSE of 0.33°, and a maximum error not exceeding 0.76° were obtained. The coefficient of determination reached a value of $R^2 = 0.999$. The results confirm that the proposed method enables precise measurement of the angle of rotation of the plane of light polarisation whilst significantly simplifying the measurement setup, reducing measurement time and lowering costs compared to solutions requiring the recording of the full optical spectrum.

Keywords: tilted fibre Bragg grating, TFBG, polarisation plane rotation, optical fibre sensors, cladding mode resonances, power-based optical interrogation

MACHINE LEARNING-BASED ALGORITHM FOR ESTIMATING ENERGY EFFICIENCY OF PHOTOVOLTAIC PANELS IN PUBLIC TRANSPORT: CASE STUDY OF LUBLIN

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Abstract: The present study investigates the energy efficiency of photovoltaic (PV) panels installed on public transport buses. The focus is on assessing urban routes for their solar energy harvesting potential and its impact on fuel consumption reduction. The analysis is based on real-world data collected from the public transport system in the city of Lublin. Due to the prevalence of GPS signal loss, particularly in dense urban environments, a machine learning-based algorithm was developed to enhance bus trajectory reconstruction. The proposed methodology comprises four main stages: (1) filtering and processing GPS data to reconstruct bus routes, (2) augmenting the dataset by computing additional metrics and factors from the original dataset, (3) dividing bus routes into hexagonal spatial units and calculating average metric values for each region, and (4) identifying areas with higher shading factors and solar energy potential for each spatial unit. The reconstruction stage uses anomaly detection techniques to mitigate the effects of incomplete or noisy GPS signals. The results indicate that several areas in Lublin are suboptimal for installing PV panels, that routes on the outskirts are less energy-intensive than those within the city, and that the issue raised in the article could help improve urban planning. Furthermore, the proposed approach facilitates the identification of spatial patterns affecting PV performance and supports data-driven decision-making for planning energy-efficient transport systems.

Keywords: energy efficiency, photovoltaic panels, machine learning, isolation forest, algorithm, public transport, spatial distribution, urban planning

IMAGE-BASED CONTACT PATCH CHARACTERIZATION OF WHEELCHAIR TIRE–ROLLER INTERACTION USING CONVEX HULL AND ALPHA SHAPE ALGORITHMS

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Abstract: This study presents a low-cost methodology for determining the contact patch geometry between a pneumatic wheelchair tire and a rigid roller using image processing and computational geometry techniques. Tire imprints were obtained using an ink transfer method and analyzed with convex hull and alpha shape algorithms. The approach enables estimation of the semi-axes of the equivalent contact ellipse and assessment of their influence on the pressure center shift x0, a key parameter in rolling resistance modeling. The results indicate that the convex hull algorithm systematically overestimates the contact geometry, particularly in the transverse direction. For irregular and highly elongated contact patches, the contact width is overestimated by approximately 15–35%, and the contact area by 20–50%. In contrast, the alpha shape algorithm provides a more accurate reconstruction of the actual contact boundary. These geometric discrepancies propagate into the analytical model, leading to an overestimation of the pressure center shift x0 by approximately 5–10% when the convex hull is applied. The findings demonstrate that accurate geometric reconstruction of the contact patch is essential for reliable modeling of tire–roller interaction and that alpha shape-based methods offer a significant improvement over conventional convex approximations.

Keywords: contact patch, image processing, alpha shape, convex hull, wheelchair tire, rolling resistance, pressure center shift, computational geometry, tire–roller interaction, low-cost measurement

PASSWORD SECURITY AMONG INTERNET USERS: AN ANALYSIS OF KNOWLEDGE, ATTITUDES, AND PRACTICES

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Abstract: This study aims to examine Internet users' knowledge, attitudes, and practices regarding password security and to identify discrepancies between actual user behaviours and recommendations provided by cybersecurity experts. The study was conducted using a questionnaire survey administered in electronic and paper form between April and June 2026. A total of 201 respondents representing different age groups, from under 18 to over 65 years of age, participated in the research. The findings indicate that most participants consider password security an important element of online account protection and demonstrate awareness of basic security principles. However, significant discrepancies were identified between declared knowledge and actual practices. Many respondents continue to reuse passwords, prioritise memorability over security, and do not fully follow current recommendations concerning password management. The results also show that users rely primarily on information obtained from Internet sources rather than recommendations from cybersecurity specialists or formal education. In addition, passwords were perceived as the most secure authentication method. A comparison with previous studies conducted in Poland suggests that users in 2026 create longer and more complex passwords than those reported in 2013. The collected survey data provide empirical insights into user behaviour that may support future analyses, cybersecurity risk assessments, and the development of models that consider human factors. The findings may also contribute to the validation of computational models that incorporate human behaviour as a factor influencing cybersecurity risk.

Keywords: password security, cybersecurity, internet users, user behavior

IMPACT OF WEBSITE INTERACTIVITY AND PERFORMANCE ON USER EXPERIENCE: AN ANALYSIS OF SELECTED WEBSITES

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Abstract: The aim of this paper is to analyze the impact of website interactivity and performance on user experience. The study evaluates how interface elements (including animations, microinteractions, and dynamic content), as well as technical performance parameters, influence user satisfaction and usability of web services. The research was conducted based on an analysis of selected websites and data obtained from the Google PageSpeed Insights tool (including LCP, FCP, and TBT metrics), complemented by the results of a user survey. A mixed-method approach was applied, combining both quantitative and qualitative analysis. The results indicate that higher technical performance correlates with improved user experience. At the same time, a high level of interactivity can increase user engagement; however, when not properly optimized, it may negatively affect usability, particularly on mobile devices. The findings highlight the need to maintain a balance between interactivity and performance in the design of modern web interfaces.

Keywords: user experience (UX), web performance, website interactivity, usability

MULTI-CRITERIA OPTIMIZATION OF UAV MEDICAL TRANSPORT CORRIDORS IN URBAN ENVIRONMENTS BASED ON COST SURFACE ANALYSIS

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Abstract: The dynamic development of medical logistics utilizing Unmanned Aerial Vehicles (UAVs) in time-critical missions requires a careful balance between operational efficiency and stringent Ground Risk Class (GRC) safety requirements within dense urban environments. This study introduces and implements a multi-criteria optimization model for autonomous Beyond Visual Line of Sight (BVLOS) medical flight corridors based on spatial cost surface analysis. The proposed methodology integrates urban planning structures with the SORA risk assessment framework. Utilizing a dasymetric mapping technique, a spatial disaggregation of demographic data was performed, shifting from homogeneous administrative districts to a continuous population presence probability model based on urban capacity indicators derived from the draft General Plan of the City of Lublin. Using the Analytic Hierarchy Process (AHP), specific weights were assigned to five operational criteria, with human exposure defined as the overriding component of the model. The final spatial resistance map was generated through Multi-Criteria Evaluation (MCE), and the optimal trajectories were calculated using the Least-Cost Path (LCP) algorithm. Validation of the model across selected healthcare facilities in Lublin demonstrated that LCP corridors reduce the operational population exposure risk (Rop) by an average of 74.38% compared to geometric shortest paths. Despite the extended trajectories, these routes guarantee a 22–40% time advantage over ground Emergency Medical Services (EMS). Furthermore, network analysis revealed that spatial optimization does not significantly affect cellular handover dynamics, maintaining a comparable frequency of network switches across both routing strategies. The developed method serves as a robust decision support tool, enabling the safe operationalization of Urban Air Mobility (UAM) networks integrated with municipal spatial planning.

Keywords: UAV, medical logistics, cost surface, GIS analysis, path planning, urban zone

SPATIALLY DETERMINISTIC DUAL-GRID CLUSTERING FOR ENERGY-EFFICIENT WIRELESS SENSOR NETWORKS IN IOT MONITORING

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Abstract: The LEACH protocol remains a foundational clustering algorithm for wireless sensor networks, yet random cluster head selection can produce uneven energy consumption and premature spatial degradation. This paper proposes G2LEACH, a dual-grid extension that separates fine-grained measurement coverage into micro-areas from coarse-grained cluster head coverage in a Grid of Head Areas (GHA). Six configurations were evaluated with 1200 static nodes over 100 independent cluster head election runs in two deployment scenarios. In the 1000 × 1000 m scenario, mean First Node Dead remained 1.00-1.03 rounds, while mean Half Nodes Alive increased from 11.0 to 59.5-116.4 rounds (+440% to +958%) and mean Last Node Dead increased from 444.6 to 830.4-932.6 rounds (+87% to +110%). In the 100 × 100 m scenario, G2LEACH-o2-v2 increased mean First Node Dead from 637.9 to 948.8 rounds (+48.7%) but reduced Half Nodes Alive and Last Node Dead by 2.1% and 2.3%, respectively. The results show that fixed spatial organization provides its strongest benefit under long-range multipath propagation, while individual variants exhibit objective-dependent trade-offs.

Keywords: wireless sensor networks, LEACH, grid-based clustering, energy efficiency, spatial coverage, network lifetime

EVALUATION OF DISTANCE METRICS FOR HUMAN POSE-LANDMARK TRAJECTORIES EXTRACTED WITH DIFFERENT POSE ESTIMATION MODELS

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Abstract: This research presents a structured methodological framework for assessing the similarity of human pose-landmark trajectories extracted from video sequences. The primary objective is to evaluate the robustness of diverse distance-based similarity measures and determine whether their multi-criteria performance ranking depends on the underlying computer vision model used for coordinate extraction. Utilizing the public Penn Action benchmark, a customized sub-dataset encompassing 853 video sequences across five distinct physical exercise classes was established. Trajectories were extracted concurrently using two state-of-the-art architectures: Google MediaPipe (BlazePose) and OpenMMLab MMPose (RTMPose-m). To ensure full methodological alignment, the output coordinates were mapped onto a unified 13-keypoint skeletal topology and converted through an agnostic spatial-temporal preprocessing layer into dense 1x2600 feature motion vectors. Pairwise similarity matrices of dimensions 853x853 were generated for ten individual distance metrics and evaluated through a dual multi-criteria scheme utilizing the global mean Silhouette coefficient and the inter/intra-class distance ratio. Instead of abstract non-parametric correlations, the framework deploys a direct structural permutation analysis of the performance hierarchies. The empirical findings reveal that while high-frequency tracking jitter and bounding-box drift introduce localized noise, the top-performing distance metrics maintain high structural stability across both vision models, undergoing only minor topological rank permutations. This stability demonstrates that optimal similarity metrics can operate as robust, model-agnostic components, paving the way for standardized and explainable analytical pipelines in vision-based human motion analysis.

Keywords: human pose estimation; pose-landmark trajectories; distance metrics; video-based movement analysis; trajectory analysis

ANOMALY DETECTION IN MAVLINK TELEMETRY LOGS OF UNMANNED AERIAL VEHICLES USING DATA ANALYTICS METHODS

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Abstract: The rapid expansion of unmanned aerial vehicles (UAVs) in logistics, agriculture, surveillance, and emergency services has increased the importance of operational safety and cybersecurity. Modern UAV platforms generate telemetry and flight log data that can be used not only for diagnostics and maintenance, but also for detecting abnormal or malicious behavior. This paper presents an approach to the analysis of MAVLink telemetry logs for identifying security-related anomalies in UAV systems. The study focuses on incidents such as GPS jumps, communication loss, battery failsafe events, abnormal trajectory changes, and suspicious command sequences. Using telemetry parameters including position, velocity, attitude, battery status, and mode transitions, the proposed methodology combines statistical analysis, rule-based methods, and machine learning techniques. The results show that MAVLink log analysis can effectively improve anomaly detection, post-incident investigation, and real-time UAV safety monitoring.

Keywords: UAV, unmanned aerial vehicles, MAVLink, Anomaly Detection

ANALYSIS OF THE POTENTIAL FOR MODIFYING SELECTED COMBUSTION PARAMETERS OF RAPESEED OIL–N-HEXANE BLENDS IN A DIESEL ENGINE BY VARYING THE START-OF-INJECTION ANGLE

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Abstract: Increasingly stringent emission regulations and directives promoting the use of renewable fuels are driving the search for diesel alternatives in compression ignition engines. The addition of n-hexane to rapeseed oil significantly reduces its viscosity, enabling common rail engine operation without structural modifications. The aim of this study was a preliminary assessment of the effect of changing the start-of-injection angle of the first pilot injection (P1) on indicated and dynamic combustion parameters of a rapeseed oil and 10% n-hexane blend (OR90Hex10). Tests were conducted on a chassis dynamometer using a Fiat Qubo 1.3 Multijet vehicle (Euro 5), with ECU control maps modified using WinOLS software. The test point corresponded to driving at 50 km/h under a 50 Nm load. The P1 start angle was varied in the range from −4 to +4°CA relative to the nominal setting, while the second pilot injection and main injection settings remained unchanged. The highest mean indicated pressure (Pi = 0.999 MPa) was obtained at nominal control. Both advancing and retarding P1 reduced Pi. Advancing P1 increased the maximum rate of pressure rise ($dp/d\alpha$) and the maximum heat release rate (Qmax), while retarding softened the combustion process. A moderate P1 retard of +2°CA provided the best compromise: it markedly reduced $dp/d\alpha$ with an acceptable decrease in Pi, and shifted the peak combustion pressure to a range characteristic of diesel operation. The results indicate that the P1 angle can serve primarily as a tool for shaping combustion dynamics rather than improving engine energy output.

Keywords: ECU remapping; common rail; rapeseed oil; pilot injection timing

MONITORING STORM SEWER DISCHARGES AND ASSESSING THE QUALITY OF RECEIVING WATERS USING MULTI-PARAMETER AND ELECTROCHEMICAL PROBES

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Abstract: Stormwater discharges are a significant source of episodic pollution affecting the ecological status of surface waters. However, their short duration and high temporal variability hinder effective monitoring and assessment of their impact on receiving water bodies. This paper presents the development and real-time validation of a modular monitoring system designed to detect stormwater discharges and assess their impact on receiving water quality using signals from multiparameter probes and electrochemical sensors. The measurement network included multi-point monitoring conducted upstream of the discharge point, in the mixing zone, and downstream of the stormwater discharge point, as well as an additional measurement point located in a sewer manhole. Continuous measurements of physicochemical parameters, such as electrolytic conductivity, pH, temperature, dissolved oxygen concentration, and turbidity, were conducted with high temporal resolution, enabling the recording of dynamic changes in water quality during rainfall events. Field data were supplemented with laboratory analyses to calibrate and validate the measurement results. Data interpretation utilized statistical and chemometric methods, as well as machine learning algorithms, to identify relationships between water quality parameters, classify discharge events, and detect changes in the aquatic environment. Principal component analysis (PCA) was used to reduce data dimensionality and identify dominant trends, cluster analysis to group similar measurement events, and LDA and PLS-DA classification models to distinguish between environmental states and assess the effectiveness of electrochemical signals in detecting storm sewer discharges. The proposed approach enabled the effective identification of short-term changes in water quality associated with storm sewer discharges and demonstrated the usefulness of "electronic tongue" signals for event classification and assessment of the aquatic environment. The obtained results confirm the potential of modular, low-cost sensor systems supported by multivariate analysis as tools for continuous environmental monitoring and early detection of pollution episodes in urban water systems.

Keywords: storm sewerage, urban pollution monitoring, pollution indicators, electronic senses

A MULTI-LAYER CYBER-PHYSICAL 3D PRINTING SECURITY FRAMEWORK FOR THE AEROSPACE AND DEFENSE INDUSTRY

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Abstract: Additive technologies are based on the numerical preparation of data for the manufacturing process, starting from the 3D-CAD model, through the processing of solid and surface model data, up to the implementation of 3D printing itself. This article presents an analysis of a multi-layered approach to 3D printing process security as a cyber-physical manufacturing system. This approach can be applied to securing data used in the production of products using additive technologies used in the aerospace, energy, and defense industries. The analysis examines the potential and risks of interference or unauthorized access to numerical data resulting from the concept of additive manufacturing itself at subsequent stages of data processing and transfer. Given that, in the case of 3D printing technology, a significant number of stages of production planning and preparation occur in a software environment, special attention is paid to these process layers. The physical aspect of the additive manufacturing process, including pre- and post-processing stages, is also analyzed. Additionally, a framework approach to information security procedures was presented in the area of physical security resulting from the organizational structure of the additive manufacturing process itself as well as of an enterprise using 3D printing to produce aerospace or space components.

Keywords: Cyber-Physical Security, 3D Printing, data processing, Multi-Layer Analysis, aerospace and defence industry

DETECTION OF ATTACKS ON COMPUTER NETWORKS USING MACHINE LEARNING - PREDICTIVE MODEL

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Abstract: Intrusion detection systems based on machine learning achieve high effectiveness under optimal testing conditions. However, real environments come with limitations such as changing data characteristics, previously unknown attacks or low and delayed label availability. To address these challenges, this paper proposed an approach of continuous adaptation to streaming data in the form of active incremental learning. This solution further incorporates a semi-supervised learning approach to reduce expert involvement. The effectiveness of the approach was assessed under conditions simulating realtime system operation. The results of the performed tests show that selective use of expert assistance maintains high classification performance while minimising labelling costs. An F1 score of 0.9930 was achieved using 6% of labels, and 0.9803 with approximately 2%, indicating that a limited number of expert labels is sufficient for effective model adaptation. These findings confirm the effectiveness of the proposed adaptation mechanism for intrusion detection in streaming environments.

Keywords: intrusion detection system, incremental learning, active learning, cybersecurity

MACHINE LEARNING MODELS TRAINED ON MULTIDIMENSIONAL GAS SENSOR SIGNALS WITH EXPLAINABLE AI INTERPRETATION FOR SURFACE WATER AND WASTEWATER CLASSIFICATION

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Abstract: In this study, the same machine learning models were applied to analyze multidimensional data obtained by a gas sensor matrix, concerning surface water and wastewater. The aim of this study was to compare the application of the same machine learning methods trained on data from different types of polluted water and to apply explainable artificial intelligence (XAI) methods to interpret the decisions made by the trained models. The performance of the mentioned methods, both supervised and unsupervised, was much better for the data from the more polluted samples and for the wastewater samples. Applying the selected unsupervised methods to the surface water data did not yield a clear separation of distinct groups for all observations. Nevertheless, the supervised methods showed greater potential for drawing conclusions – the vast majority of observations were correctly classified to the true location of the sampling point. However, the accuracy of the supervised models trained on the data derived from wastewater samples is higher than the accuracy of the models trained on surface water samples. To better understand the basis of these classification outcomes, several XAI techniques were employed to identify which sensor signals and features contributed most significantly to models' predictions, providing greater interpretability of the obtained results.

Keywords: multidimensional data analysis, machine learning, gas sensor array, explainable artificial intelligence (XAI), surface water, wastewater

ENTROPY-BASED ANALYSIS OF ACTIVATED SLUDGE PARAMETERS

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Abstract: Activated sludge constitutes a complex microbial ecosystem the spatial organization and community structure of which play a crucial role in the effectiveness of bioreactor performance. Conventional assessments of activated sludge are primarily based on microscopic observations of floc morphology and the identification of bioindicator organisms. Although floc size can be quantified relatively easily, the objective characterization of floc shape and microbial community structure remains challenging. Therefore, there is a growing demand for quantitative and reproducible analytical methods capable of supporting traditional biological approaches. This study applied mathematical methods derived from information theory, with particular emphasis on entropy-based metrics, to characterize and compare both the geometric properties of activated sludge flocs and the structure of associated microbial communities. Activated sludge samples were collected from various stages of the technological line at the Hajdów wastewater treatment plant in Lublin, Poland. Microscopic observations were performed with a standard biological microscope, and digital photographic documentation was acquired for subsequent image analyses. Based on the collected data, selected metrics, including Shannon entropy and related statistical metrics, were calculated and compared across sampling locations to evaluate the differences in floc morphology and microbial community composition. The obtained results demonstrate the potential of entropy-based metrics for the quantitative assessment of activated sludge structure and for distinguishing between different operational conditions within the biological factor of the treatment process. The proposed approach may contribute to the development of advanced tools for wastewater treatment monitoring and process control. Furthermore, the integration of quantitative entropy-based analytical methods with modern artificial intelligence techniques, particularly deep-learning-based image analysis, offers significant potential for the automated detection, classification, and quantification of microscopic objects. Such integration could substantially reduce the time required for biological process assessment while providing rapid, objective, and cost-effective quantitative data to support wastewater treatment management.

Keywords: Entropy-based analysis, activated sludge parameters, flock size and shape, community structure, automated image analysis

AMPLITUDE-RANGE REFLECTANCE TOMOGRAPHY FOR ENERGY-EFFICIENT INDOOR OBJECT TRACKING

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Abstract: This paper presents an energy-efficient, non-intrusive system for indoor object detection and tracking based on reflection tomography. The proposed architecture combines distributed ceiling-mounted microwave probes with a central localization engine. Each probe integrates a 10.585 GHz continuous-wave radio unit, an array antenna, an STM32 F4 microcontroller, a 12-bit analog-to-digital converter, and CAN-bus communication. Motion is captured through Doppler-induced variations in the returned signal, enabling the sampling rate and measurement schedule to be reduced or adapted while preserving measurement resolution. A forward model simulates complex continuous-wave responses for direct and wall-reflected propagation paths with additive noise. The inverse stage uses measured amplitudes only and therefore does not require phase information. For every candidate grid point, range-dependent Gaussian weights are accumulated over antennas and time samples and normalized to generate a spatial probability map. Numerical examples illustrate the reconstruction of a moving target trajectory and the antenna-dependent behavior of estimated ranges. The resulting hardware-algorithm framework demonstrates the feasibility of combining low-power distributed sensing with amplitude-only localization in rooms containing architectural obstacles. Its principal strengths are non-visual operation, adjustable data acquisition, and a favorable balance among localization capability, communication load, and energy consumption. The simplified inverse model does not explicitly compensate for phase or multipath reflections, indicating the main direction for further improvement and experimental validation.

Keywords: Reflection Tomography, Indoor Localization, Object Tracking, Doppler Sensing, Amplitude-Only Reconstruction, Microwave Sensors, CAN Bus, Energy-Efficient Sensing

PHYSICS-CONSTRAINED UNROLLED RECONSTRUCTION OF SLOWNESS MAPS IN ULTRASOUND TRANSMISSION TOMOGRAPHY

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Abstract: This study introduces an interpretable physics-constrained framework for reconstructing two-dimensional slowness maps in transmission ultrasound tomography using only time-of-flight (ToF) measurements. The inverse problem is formulated with a differentiable straight-ray projection operator, providing a controlled baseline between data fidelity and learned image regularization rather than full-waveform inversion. The method initializes the image by Tikhonov regularization and unfolds eight proximal iterations. Each iteration combines the explicit data-consistency gradient A^T(Ax - y) with a bounded residual correction predicted by a measurement-conditioned U-Net. The network receives the current estimate, Tikhonov image, data-consistency map, backprojection, previous residual, and field-of-view mask, while auxiliary heads estimate inclusion masks and boundaries. Training employs image, foreground, edge, segmentation, data-consistency, and deep-supervision losses. Evaluation on 512 synthetic validation cases showed that fine-tuning the mask head produced the strongest deployable variant, reaching a PSNR of 26.2371 dB, Dice of 0.9148, IoU of 0.8489, boundary IoU of 0.7246, and mean absolute data-consistency error of 0.000351. Boundary-focused calibration increased boundary IoU to 0.7272 but slightly reduced global mask IoU, revealing a contour-versus-region trade-off. A diagnostic oracle-gated residual denoiser reached approximately 26.596 dB PSNR, indicating remaining local amplitude-correction capacity but no deployable solution to topology errors. The results show that embedding an explicit forward operator in an unrolled network yields stable, measurement-consistent reconstructions from information-limited ToF data and provides a reproducible baseline for future models using waveform, amplitude, phase, or multi-feature measurements.

Keywords: ultrasound transmission tomography, time of flight, inverse problems, physics-guided deep learning, unrolled optimization, proximal reconstruction, data consistency

MATRIX-FREE RECONSTRUCTION FOR PORTABLE 3D ULTRASONIC NDE

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Abstract: Portable three-dimensional ultrasonic non-destructive evaluation requires volumetric reconstruction under severe memory, computational, and thermal constraints. This study presents an edge-oriented imaging pipeline that reconstructs spatial reflectivity directly from raw radio-frequency data on a Raspberry Pi 5. Under the First Born approximation, the inverse problem is implemented as a matrix-free adjoint operation; compact delay and weighting tables replace an explicit system matrix exceeding 5 GB for 1024^2 grids. Radio-frequency signals are quantized to signed INT8 values, accumulated in 32-bit registers, and processed by parallel Just-In-Time compiled kernels on four Cortex-A76 cores. The prototype combines a 32-element, 2 MHz linear array, 32-channel acquisition over USB 3.0, band-pass filtering with time-gain compensation, and OpenGL-based 3D maximum-intensity-projection visualization. Performance was assessed using tissue-mimicking and resin-aluminum phantoms against a Float32 baseline. INT8 processing reduced reconstruction latency from 172.4 ms to 7.0 ms and increased reconstruction throughput from 5.8 to 142.7 frames per second, corresponding to approximately a 24-fold speedup. End-to-end pipeline latency fell from 384.6 ms to 27.0 ms, while throughput increased from 2.6 to 37.0 frames per second. Reconstructed images achieved 34.9 dB PSNR and exhibited negligible visual degradation relative to Float32 output. The results demonstrate that matrix-free integer reconstruction can support real-time 3D ultrasonic inspection on low-cost embedded hardware without materially compromising image quality. The proposed architecture provides a practical basis for handheld field-deployable NDE systems and further edge-based ultrasonic imaging research.

Keywords: ultrasonic non-destructive evaluation, 3D imaging, Raspberry Pi 5, matrix-free reconstruction, INT8 quantization, JIT compilation, edge computing, real-time imaging

PHYSICS-INFORMED IDENTIFICATION OF RADIAL CLEARANCE IN A NONLINEAR 4-DOF ROLLING BEARING MODEL

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Abstract: Radial internal clearance strongly influences the nonlinear dynamic response of rolling element bearings and is therefore an important parameter in condition monitoring and predictive maintenance. This study develops a physics-informed neural network (PINN) framework for inverse identification of bearing clearance in a strongly nonlinear 4-DOF dynamic model. The proposed formulation extends reduced bearing models by explicitly describing the horizontal and vertical motion of both the shaft and the bearing housing, while the interaction between the two subsystems is governed by intermittent nonlinear Hertzian contact. The PINN is trained to simultaneously reconstruct the four displacement responses and estimate the unknown radial clearance by embedding the governing equations of motion directly into the loss function. Synthetic reference responses generated using a 4th-order Runge-Kutta solver are used for numerical validation. The robustness of the proposed approach is additionally evaluated under different levels of noise in order to assess its suitability for future application to experimental vibration measurements. For the investigated operating condition, the identified clearance converges to the prescribed reference value with a relative error of approximately 0.008%. Moreover, the reconstruction error of the four-dimensional dynamic response remains below 0.05% even for a 10% noise level. These results demonstrate that the PINN-based inverse formulation retains high parameter-identification accuracy despite increased model complexity and measurement uncertainty. The developed 4-DOF framework provides a basis for future identification of bearing operating parameters directly from experimental vibration signals.

Keywords: Physics-informed neural networks; rolling element bearing; radial internal clearance; nonlinear dynamics; parameter identification

DESIGN AND DEVELOPMENT OF AN INTEGRATED TEST BENCH FOR VIBRATION ENERGY HARVESTING WITH A MEASUREMENT AND CONTROL SYSTEM

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Abstract: The experimental investigation of piezoelectric vibration energy harvesting systems requires dedicated test benches capable of providing controlled mechanical excitation and accurate measurement of electrical responses. This paper presents the design and development of a modular test bench and an integrated measurement and control system for evaluating piezoelectric energy harvesters. The mechanical structure was designed in SolidWorks and incorporates a supporting frame, an excitation system, mounting components, and interchangeable elements enabling different experimental configurations. Particular attention was paid to mechanical adaptability, accessibility of measurement points, and repeatability of experimental conditions. A measurement and control application was developed in LabVIEW to configure excitation parameters, monitor measurement signals in real time, acquire and record experimental data, and perform preliminary signal processing. The proposed measurement architecture supports the acquisition of mechanical and electrical parameters, including vibration frequency, amplitude, and generated voltage, as well as the determination of electrical power under defined load conditions. The combined mechanical and software architecture provides a configurable experimental platform for investigating the influence of operating conditions on piezoelectric energy conversion. The developed system establishes a basis for subsequent experimental validation, comparison of different harvester configurations, and optimisation of energy harvesting performance.

Keywords: piezoelectric energy harvesting, experimental test bench, mechanical excitation, data acquisition, measurement and control system

ARTIFICIAL AND COMPUTATIONAL INTELLIGENCE

EXPLAINABLE CNN-BASED BOTTLENECK DIAGNOSIS IN HUMAN–COBOT MANUFACTURING USING PROCESS HEATMAPS: AN OPERATIONS AND QUALITY MANAGEMENT PERSPECTIVE

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Abstract: Human–robot collaborative manufacturing, positioned at the core of the Industry 5.0 paradigm, increases the stochasticity of production systems through human variability, safety-related stops, and resource-sharing constraints. In such environments, rapid identification of dominant bottlenecks and their root causes is critical to operational resilience, production-management responsiveness, and preserving the human-centric character of operations. This study proposes an explainable bottleneck-diagnosis framework based on convolutional neural networks (CNNs) that leverages process heatmaps derived from a discrete-time flow-line simulation model inspired by the digital twin concept. Each simulation run is encoded as a three-channel heatmap (queue length, station busy state, and downtime), yielding a compact spatio-temporal "process fingerprint" suitable for image-based representation learning. We consider a six-class taxonomy: balanced operation, bottleneck caused by human fatigue, bottleneck caused by cobot performance degradation, bottleneck caused by safety stops in a human–cobot cell, bottleneck caused by robot failure, and supply delays (line starvation). On a balanced dataset of 1,500 synthetic samples, the CNN achieves a test accuracy of 0.938 (macro-F1 = 0.938; 95% Wilson confidence interval for accuracy: 0.898–0.963). An ablation study shows that multi-channel heatmaps improve accuracy by 0.10 compared with queue-only heatmaps. Explainability is operationalised using Gradient-weighted Class Activation Mapping (Grad-CAM), which consistently localises station–time regions associated with queue build-up and downtime patterns, providing process engineers with evidence that can be translated into corrective actions. The results indicate that simulation-generated heatmaps can support transparent and scalable bottleneck analytics for human–cobot manufacturing, enabling rapid prototyping prior to deployment on shop-floor data and providing an evidence-based decision-support instrument for operations and quality management.

Keywords: digital twin; simulation; Industry 5.0; human–robot collaboration; bottleneck diagnosis; process heatmaps; convolutional neural networks; explainable artificial intelligence; Grad-CAM; operations management; quality management

MACHINE-LEARNING-BASED PREDICTIVE CONTROL OF ANAEROBIC DIGESTION CONSIDERING METEOROLOGICAL CONDITIONS

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Abstract: Efficient control of the anaerobic digestion process in municipal wastewater treatment plants poses an engineering challenge due to the high inertia of the system and the impact of uncontrolled external disturbances. This paper presents a novel approach to optimizing feedstock composition (the ratio of primary to excess sludge) to maximize biogas production. Unlike classical control methods, the proposed solution accounts for the impact of exogenous factors ambient temperature and precipitation which determine the physicochemical parameters of raw sludge. To build an effective model on a limited dataset, a spatial disaggregation technique was applied, merging data from four parallel digestion chambers. A hybrid decision-making system was developed, integrating a random forest model with a genetic algorithm (GA). The resulting predictive model achieved accuracy ($R2 = 0.77$, $MAPE = 7.33$) under LODO validation, indicating that incorporating time delays in weather data allows for precise prediction of efficiency drops. The application of the evolutionary algorithm in a one-day numerical case study enabled the determination of optimal operational setpoints, indicating the potential for increased energy yield under difficult environmental conditions. Rather than a real-time autonomous control system, the presented solution constitutes a predictive optimization framework and a functional module for a decision support system (DSS), enabling a transition from reactive to prescriptive strategies.

Keywords: biogas, anaerobic digestion, genetic algorithms, machine learning, predictive control, process optimisation

FORECASTING CO_2 EMISSIONS FROM SOILS AMENDED WITH SEWAGE SLUDGE BIOCHAR USING ARTIFICIAL NEURAL NETWORKS

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Abstract: The aim of this study was to develop neural models to forecast CO_2 emissions from soils amended with sewage sludge biochar and to determine the impact of input variable selection on modeling quality. The analysis was based on data from a 36-day experiment on sandy soil and chernozem, with varying biochar application rates and production temperatures. Modeling was performed using Statistica software with MLP-type artificial neural networks trained via the BFGS algorithm. The output variable was the soil CO_2 emission flux. Five variants of input variable sets were analyzed: (1) a full set of 16 parameters, including biochar application rate, pyrolysis temperature, soil type, incubation time, carbon forms: total (TOC), residual (ROC), and dissolved (DOC), pH, total nitrogen, nitrate nitrogen ($N–NO_3$), ammonium nitrogen ($N–NH_4$), and the content of phosphates, sodium, magnesium, potassium, and calcium; (2) four experimental parameters: biochar application rate, pyrolysis temperature, soil type, and incubation time; (3) three forms of organic carbon: TOC, ROC, and DOC; (4) three forms of nitrogen: total, $N–NO_3$, and $N–NH_4$; and (5) pH and the content of phosphates, sodium, magnesium, potassium, and calcium. Networks with different numbers of input and hidden neurons were compared by evaluating the agreement between modeled values and measured results. The MLP 16–3–1 model, incorporating the full set of input variables, achieved a correlation coefficient of $R = 0.70$. For the model using four experimental parameters, $R = 0.77$ was obtained. Thus, limiting the set of input variables resulted in a higher correlation coefficient. In this comparison, the inclusion of additional physicochemical parameters did not improve the network model's quality.
The results indicate that the ANN model can serve as a useful tool for estimating CO_2 emissions.

Keywords: mathematical modeling, artificial neural networks, MLP, input variable selection, CO_2 emissions, biochar

A DETERMINISTIC MEMORY ARCHITECTURE FOR LARGE LANGUAGE MODELS (LLM) WITH KNOWLEDGE LIFECYCLE MANAGEMENT (KLM)

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Abstract: Large language models lack built-in mechanisms for persistent and verifiable memory, leading to factual inconsistencies in long interaction sequences. Unlike the Retrieval-Augmented Generation (RAG) technique, which relies on vector similarity without explicit knowledge lifecycle management, and the MemGPT architecture, which delegates memory management to the language model itself, the proposed architecture separates these responsibilities. Memory evolution proceeds deterministically through mechanisms of activation decay, reinforcement, and threshold-based archival, while higher-layer consolidation results are made available only upon detection of actual structural change. The language model closes the feedback loop – automatically detected signals from natural user reactions modify the activation of memory nodes. This paper describes a designed and implemented memory system architecture in which knowledge is represented as structured knowledge nodes with quantitative activity and reliability parameters. Activation decays exponentially over time, following the Ebbinghaus forgetting curve, and increases with the number of node confirmations — the reinforcement mechanism is inspired by the ACT-R base-level activation model. The system organizes knowledge across four layers: L1 stores knowledge nodes with full quantitative parameters; L2 records snapshots of thematic scope state; L3 generates temporal summaries, made available in the response context only upon detection of structural divergence between snapshots; L4 stores critical facts subject to automatic revalidation and archival when activity and reliability criteria are no longer met. Query routing deterministically directs queries along one of two paths: for queries about known facts, the response is drawn directly from memory layers; for all others, the language model generates a response based on a structurally compressed memory context and the relation graph. The result is a working prototype of a memory system with functional knowledge lifecycle mechanisms: ingestion, consolidation, promotion, and fact revalidation. Preliminary tests indicate the potential to reduce factual inconsistencies in multi-session interactions without increasing the model's context window.

Keywords: Large Language Models (LLMs), Memory Architecture, Knowledge Lifecycle Management, Factual Consistency, Knowledge Representation, Deterministic Systems, Context Management

INVERSE DESIGN OF MULTIRING OPTICAL FIBRES USING MACHINE LEARNING FOR BEAM SHAPING APPLICATIONS

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Abstract: Recent advances in machine learning have shown strong potential to accelerate the design of optical fibres by predicting beam characteristics from structural parameters. However, practical applications often require the inverse approach, in which desired beam properties are specified a priori and the corresponding fibre configuration must be determined. This study proposes an inverse design framework for multiring optical fibres using machine learning techniques. Building on a dataset of numerically simulated fibre configurations and their corresponding beam characteristics, including beam flatness, edge steepness, and full width at half maximum (FWHM), an inverse mapping is developed to predict fibre parameters from target beam specifications. Unlike conventional forward models, which estimate beam properties from refractive index profiles, the proposed approach addresses the more challenging inverse problem, which is inherently non-unique and ill-posed. Several machine learning strategies, including single- and multi-target regression models, are examined to determine whether beam parameters should be predicted jointly or independently. The study also assesses the impact of feature selection and parameter representation on the stability and accuracy of the inverse model. Particular attention is paid to the role of derived geometric descriptors of the refractive index profile, which have previously been shown to significantly influence forward prediction performance. Preliminary results indicate that the inverse model can identify fibre configurations that produce beam characteristics close to the desired specifications, significantly reducing the need for exhaustive numerical simulations. The proposed framework provides a foundation for automated fibre design and demonstrates the feasibility of machine- learning-assisted inverse engineering for photonic structures.

Keywords: machine learning, photonic design, inverse design, multiring optical fibres, beam shaping, data-driven modelling

CUSTOM RECURRENT-BASED FRICTION PREDICTION IN A WEAR-RESISTANT HARDFACING ALLOY

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Abstract: Predicting tribological behaviour in multi-component wear-resistant alloys is difficult because of their complex microstructure and the nonlinear phenomena in the contact zone. The Fe–Mn–C–B–Si–Ni–Cr coating combines hard carbide (Fe_3C, Cr_7C_3) and boride (Fe_2B, FeB) phases with a ductile austenitic–martensitic matrix. A custom recurrent neural network predicts its friction behaviour. Tribological tests were performed on a high-temperature ball-on-disc tribometer (THT 1000, Anton Paar), which continuously recorded the coefficient of friction (COF). Because point-wise analysis could not capture the dynamic nature of wear, raw time-signals were processed with a moving-window technique to extract statistical descriptors. A custom two-branch recurrent network, TriboRNN, was developed. The recurrent branch comprises a bidirectional GRU (Gated Recurrent Unit) followed by an LSTM (Long Short-Term Memory) with additive attention. It processes the descriptors, whereas a dense branch encodes static alloy and process parameters. The model achieved a pooled R^2 (coefficient of determination) of 0.911 and an RMSE (Root Mean Square Error) of 0.0312 on the withheld test set. It matched a stacked-LSTM baseline in accuracy but proved far more reproducible. Its seed-to-seed variance was roughly an order of magnitude lower. The method predicts the friction behaviour of iron-based hardfacing systems and helps address the limited datasets that constrain tribological research.

Keywords: artificial intelligence, recurrent algorithms, attention mechanism, coefficient of friction, coated alloy

TRAINING MACHINE LEARNING AGENT BEHAVIORS IN UNITY: PROXIMAL POLICY OPTIMIZATION VS. SOFT ACTOR-CRITIC ALGORITHMS

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Abstract: The gaming evolution is strictly associated with machine learning development, such as Reinforcement Learning. Thus, there is an ongoing need to study and apply machine learning algorithms to games to achieve human-like agent behavior. Among various algorithms, Proximal Policy Optimization (PPO) and Soft Actor-Critic (SAC) are among the state-of-the-art reinforcement learning methods. They have been widely adopted due to their optimal balance of performance, stability, and ease of implementation. Factors such as the test environment, reward function, neural network architecture, and computational resource availability significantly influence the relative performance of both algorithms. Thus, the main aim of our study is to analyze PPO and SAC reinforcement learning methods across three Unity-created environments, using parallel learning with discrete and continuous actions. SAC performed better in simpler scenarios, whereas PPO achieved better results in more complex environments. The ablation study assesses hyperparameter sensitivity. Batch size had a stronger impact on SAC performance, whereas buffer size had a stronger impact on PPO.

Keywords: Unity, ML-Agents, PPO, SAC

AUTOMATIC METHODS FOR 3D MOTION TRAJECTORIES GAP FILLING: CUSTOM-BASED KALMAN VS. BILSTM

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Abstract: Modern data analysis increasingly relies on time series data across diverse domains, such as biomechanics, medicine, sports, and computer animation. A special case of this data type is one generated from optical motion capture systems, enabling the precise spatiotemporal tracking of anatomical marker positions. However, during dynamic and fast movement recordings, some markers may not be registered properly, mainly due to their obscuration or an insufficient number of cameras. While continuous trajectories provide the basis for human movement analysis, their utility is heavily dependent on the accurate registration of all measurement points. The post-processing of motion capture data is highly time-consuming, thus, adjusting the appropriate and highly reliable gap-filling method is extremely important for further data analysis. In this study, we propose a novel, custom-based Kalman filter for gap filling of dance motion capture trajectories. This method integrates the three-dimensional positions of markers, their velocities, and accelerations. The proposed method is compared with the basic Kalman filter and a bidirectional Long Short-Term Memory (BiLSTM) model, which is highly effective for sequential data imputation. Given these dual paradigms, this study aims to compare the classical mathematical model with the modern machine learning approach in the context of motion capture data reconstruction, evaluating their respective effectiveness across varying spatial and temporal characteristics of missing data. Several examinations, based on the number of missing markers (from 2 to 14) in the given marker's neighbor group across various frame numbers (from 100 to 500), were performed. The BiLSTM model achieved lower RMSE values than the custom Kalman-based filter in almost all scenarios and was also highly stable for a small number of missing markers. However, the accuracy of both methods deteriorated with a large number of missing markers, indicating a significant impact of the spatial distribution of missing data on reconstruction quality.

Keywords: Kalman filter, BiLSTM, motion capture, gap filling

ADVANCES IN AUTOMATIC SEEDLING DETECTION AND LOCALIZATION USING CNN-BASED COMPUTER VISION FOR PRECISION WEED CONTROL IN PRECISION AGRICULTURE

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Abstract: It can be observed that dynamic developments in artificial intelligence are contributing to the evolution of existing techniques used in agricultural research and crop protection systems. Currently, innovative methods are being sought to support unit processes such as precision agrochemical application, while at the same time monitoring crop health and reducing herbicide usage. The development of innovative technology using convolutional neural networks (CNNs) for the automatic detection, classification, and localization of plant seedlings seems highly desirable. This will translate into obtaining localized spot-spraying capabilities based on the specific morphological structure and geometric positioning of the young plants. This study aims to apply convolutional neural networks to the classification and precise localization of radish, parsley, and cress seedlings, supported by comparative image processing using the LAB and HSV color spaces combined with Otsu thresholding. The results show that LAB-based segmentation using *a* channel is highly effective and stable when identifying plant morphological structures using CNNs, particularly under challenging illumination conditions. The use of CNNs, contour analysis, and geometric center (centroid) calculations together with dataset expansion via Auxiliary Classifier Generative Adversarial Networks (AC-GAN) shows the most favorable results. The best results were obtained for a sample during the intermediate growth stage (5–12 days) under sunny conditions, where the LAB-based approach achieved a precision of 0.89, recall of 0.84, and accuracy of 0.93. The CNN model achieved an overall classification accuracy of 93% on a balanced dataset comprising over 1,200 samples generated from approximately 60 original field images using AC-GAN, confirming its effectiveness for the classification of seedling microstructures under realistic field conditions.

Keywords: seedling identification; spot-spraying, image segmentation (LAB, HSV); convolutional neural networks (CNN); auxiliary classifier generative adversarial networks (AC-GAN); precision agriculture.

PARAMETER IDENTIFICATION OF A DYNAMIC SYSTEM UNDER RANDOM EXCITATION USING NEURAL NETWORKS

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Abstract: This paper focuses on identifying physical parameters of a mechanical system subjected to random excitation. Stochastic signal is the only input, which eliminates classical harmonic or impulse test signals. A large synthetic dataset is generated by numerically simulating the mechanical quarter Unmanned Ground Vehicle (UGV) model across a wide range of stiffness and damping values under band-limited white noise excitation with additive measurement noise. The Power Spectral Density (PSD) of the measured response is computed using Welch's estimator and used as a feature vector. A multilayer perceptron (MLP) regression model is subsequently trained to map the spectral features to the physical parameters (c, k). Results demonstrate that the machine learning-based approach achieves high accuracy while offering robustness to measurement noise. The performance of the proposed method is evaluated in terms of selected assessment quality indicators. The influence of selected parameters on identification accuracy is systematically investigated, providing practical guidelines for future experimental studies.

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Keywords: system identification, dynamical system, UGV, quarter model, random excitation, machine learning, neural network, parameter estimation

ANALYSIS OF THE IMPACT OF NATURAL LANGUAGE SELECTION IN LARGE LANGUAGE MODELS (LLMS) ON ENERGY CONSUMPTION

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Abstract: Large Language Model (LLM) inference is computationally intensive, yet the extent to which the interaction language affects energy consumption remains insufficiently understood. This study investigates whether inference energy consumption varies across six European languages: Polish, English, German, French, Spanish, and Russian. Three open-weight models, Llama3.1-8b, Gemma-3-12b, and Qwen2.5-14b, were evaluated using ten semantically equivalent prompts, each translated into the six languages and repeated three times. Experiments were conducted on a workstation-class server equipped with an AMD Radeon RX 7900 XT GPU and the Ollama inference framework. Whole-system power consumption was measured using a calibrated HIOKI PW3337 power meter, and energy efficiency was expressed as energy per generated token (EPT). Mean EPT varied substantially among models: Llama3.1-8b consumed 6.43 J/token, Qwen2.5-14b 10.23 J/token, and Gemma-3-12b 10.87 J/token. Kruskal–Wallis tests identified statistically significant between-language differences only for Llama3.1-8b; no significant differences were found for Qwen2.5-14b or Gemma-3-12b. However, regression analysis for Llama3.1-8b showed that response length was the dominant predictor of EPT, as fixed inference overhead was amortized over longer outputs. The findings indicate that apparent language-dependent differences in inference energy are driven primarily by generated-output length rather than by language itself. Energy efficiency also depends strongly on model architecture, tokenizer behavior, and inference implementation, highlighting the importance of response-length control and whole-system measurement in Green AI benchmarking.

Keywords: energy consumption, large language models, natural language processing, LLM, tokens

LIMITED-RESOURCE GENERALISATION IN FOLK MUSIC RECOGNITION USING MULTIMODAL ADAPTIVE ATTENTION

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Abstract: Computer Vision is an effective tool for identifying rare folk music, which is crucial for preserving intangible cultural heritage by accurately recognising characteristic songs. Artificial intelligence-enabled music detection remains an intricate issue. Thus, we propose a cutting-edge neural network architecture for Polish folk music classification, a CNN-based model with an Adaptive Attention Module (CNN AAM). It comprises an adaptive trunk branch, an adaptive mask branch, and an adaptive gate, allowing the model to adjust the attention mechanism based on the most relevant sound features. Furthermore, the proposed approach addresses challenges related to limited and imbalanced folk music datasets. As an input for the proposed architecture, Mel spectrograms, spectrograms, scalograms, and Mel-Frequency Cepstral Coefficients plots have been gathered, demonstrating various features of 3-second audio recordings. This study uses a dataset of music from Polish national dances, including the Polonez, Oberek, Mazur, Krakowiak, and Kujawiak. The obtained accuracy results are incredibly promising, reaching over 95%. The effectiveness of the developed model is compared with the state-of-the-art classifiers. Moreover, the impact of each input is verified during ablation studies. Our approach demonstrates that the CNN AMM significantly outperforms typical content-based music models.

Keywords: computer vision, machine learning, convolutional neural networks, adaptive attention module, music recognition

MACHINE LEARNING CLASSIFICATION OF ION-IMPLANTED INCONEL 718

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Abstract: Ion implantation induces complex modifications in the near-surface region of metallic materials, affecting their mechanical and tribological behavior in a non-linear and depth-dependent manner. Detecting and interpreting these changes using conventional analysis methods becomes particularly difficult when implantation-induced tribological effects are subtle or partially masked by test conditions. This study presents a machine-learning-based classification approach for Inconel 718 implanted with nitrogen ions (N^+) at 80, 120, and 160 keV and fluences ranging from 1×10^{15} to 1×10^{17} ions/cm^2. A dedicated feature engineering pipeline was developed to integrate multi-source experimental data, including coefficient of friction (COF) time-series, COF dip-event descriptors, nanoindentation parameters (HIT, EIT, HVIT), and SRIM-derived ion-damage profiles, into a unified feature representation for each sample. Random Forest classifiers were trained for four classification tasks: implanted versus reference samples, fluence classification, implantation energy classification, and combined fluence–energy classification. Within the adopted train–test evaluation framework, all classification tasks resulted in perfect separation of the analyzed classes. Feature importance analysis indicated that nanoindentation-derived parameters, particularly HIT and HVIT, provided the strongest contribution to classification performance. Additional experiments performed using exclusively tribological features (COF and dip-event descriptors) resulted in a substantial decrease in classification accuracy (~0.5–0.6), demonstrating that friction signals alone do not sufficiently represent the structural and mechanical modifications introduced by ion implantation. The results indicate that integrating tribological, mechanical, and implantation-related descriptors significantly improves the ability of ML models to identify implantation conditions and distinguish subtle material modifications. The proposed approach demonstrates the potential of machine learning methods for analysis and classification of ion-implanted materials and provides a scalable framework for integrating heterogeneous experimental datasets in surface engineering research.

Keywords: Inconel 718, ion implantation, machine learning, tribology

ADAPTIVE TOLERANT V-DETECTOR WITH DETECTOR-SPECIFIC NEIGHBORHOOD SELECTION FOR ANOMALY AND INTRUSION DETECTION

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Abstract: The Tolerant V-Detector extends the classical V-Detector by introducing a tolerance regioncontrolled by the neighborhood parameter k. Conventional implementations typically use asingle global k for all detectors, although local self-neighbor distance structures may differ.This paper proposes an adaptive neighborhood-selection mechanism that determinesdetector-specific ranks kj during offline detector configuration. The method analyzes relativechanges between consecutive self-neighbor distances using a threshold τ and persistenceparameter p, while preserving the original three-valued classification procedure.Experiments on NSL-KDD, Kyoto 2006+, and UNSW-NB15 compared the adaptive methodwith a broad range of fixed-k configurations over 15 independent detector-generation runs. Theresults show that no single configuration is optimal across all datasets. Selected adaptive settingsachieved detection performance comparable to nearby fixed-k configurations while significantlyreducing false alarm rates on NSL-KDD and UNSW-NB15, whereas on Kyoto 2006+ oneadaptive setting achieved both higher detection rate and lower false alarm rate.The proposed approach therefore reduces dependence on a single population-wide neighborhoodrank while retaining τ and p as global control parameters.

Keywords: artificial immune systems; negative selection algorithm; V-Detector; intrusion detection; anomaly detection; adaptive neighborhood selection

EFFECT OF BODY MASS INDEX ON KNEE JOINT VIBROARTHROGRAPHIC SIGNAL PARAMETERS

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Abstract: Vibroarthrography (VAG) is a non-invasive method based on the analysis of mechanical vibrations generated within a joint during movement and is finding increasingly widespread application in musculoskeletal diagnostics. A significant challenge in VAG signal analysis is the variability of recorded signals between subjects, which may be influenced by biomechanical and biological factors. Increased Body Mass Index (BMI) is associated with greater mechanical loading of the knee joint, which may alter soft-tissue properties and, consequently, affect vibration transmission and the acoustic characteristics of vibroarthrographic signals. Therefore, BMI may influence signal propagation and the damping of tissue vibrations during knee joint movement. This study aims to analyse the effect of BMI on selected vibroarthrographic signal parameters recorded during knee joint movement. The study was conducted on a group of adults aged 18-26, divided into BMI-related groups. The participants reported no knee pain or dysfunction and had not undergone any prior knee surgery. The signals were recorded using a multi-sensor measurement system during movements performed in the open-kinetic chain (OKC) and closed-kinetic chain (CKC). The acquired data were subjected to preprocessing procedures, including artefact reduction and signal filtering, followed by selected signal parameter extraction and statistical analysis. The presented study may contribute to a better understanding of the influence of biomechanical and biological factors on vibroarthrographic measurements and support further work on the standardisation and interpretation of VAG-based diagnostic methods in clinical practice.

Keywords: vibroarthrography, VAG, biomedical signal processing, body mass index, knee joint, signal analysis, biomechanics

RESTING-STATE EEG ACTIVITY AND ITS ASSOCIATIONS WITH SELECTED DIMENSIONS OF PSYCHOLOGICAL FUNCTIONING

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Abstract: Psychological disorders and anxiety-related conditions are commonly assessed using self-report questionnaires and clinical observations; however, these approaches often lack objective neurophysiological markers that could support the identification of anxiety-related processes. Electroencephalography (EEG), particularly resting-state EEG, has emerged as a valuable non-invasive method for investigating neural activity associated with emotional and cognitive functioning. Due to its high temporal resolution, resting-state EEG enables the assessment of spontaneous brain activity under both eyes-open and eyes-closed conditions, providing insight into neural mechanisms potentially related to anxiety and psychological functioning. In the present study, resting-state EEG activity was examined in relation to selected dimensions of psychological functioning and anxiety-related characteristics. EEG recordings were obtained during both eyes-closed and eyes-open resting-state conditions. To complement the neurophysiological measurements, participants completed standardized psychological questionnaires, including the NASA Task Load Index (NASA-TLX), EAS-D, State–Trait Anxiety Inventory (STAI), and Beck Depression Inventory (BDI-II). EEG signals were preprocessed in MATLAB using signal processing procedures, including band-pass filtering and artifact reduction to minimize noise related to eye movements and muscle activity. Spectral analysis was subsequently performed to extract quantitative EEG features, including power estimates within conventional frequency bands (delta, theta, alpha, and beta). Participants were categorized according to anxiety severity levels based on questionnaire scores, enabling comparative analyses between individuals presenting elevated anxiety symptoms and healthy controls. Statistical analyses were conducted to identify associations between EEG-derived features and psychological measures related to anxiety, depressive symptoms, emotional functioning, and perceived cognitive workload. The proposed computational workflow enabled systematic processing of multidimensional neurophysiological and psychometric data and may contribute to the identification of EEG-based markers of anxiety. Furthermore, the presented approach demonstrates the applicability of EEG signal processing and biomedical data analysis methods in the development of computer-aided systems supporting the objective assessment of anxiety-related conditions.

Keywords: electroencephalography, anxiety disorder, resting-state EEG, brain activity, EEG biomarkers, neurophysiological markers

THCS-VIT: A HYBRID LIGHTWEIGHT VISION TRANSFORMER WITH MULTI-SCALE FEATURE FUSION FOR THERMAL FACIAL EMOTION RECOGNITION

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Abstract: Thermal facial images pose serious challenges for classical convolutional networks and standard transformer architectures due to their low contrast, significant sensor noise, and lack of rich textural details. In this paper, we propose THCS-ViT (Thermal Hybrid Cross-Scale Vision Transformer), a hybrid architecture integrating a lightweight convolutional stem inspired by MobileNetV3, a Cross-Scale Attention Fusion (CSAF) module, and a modified MobileViT-S backbone. The model was trained on the KTFEv2 (Korean Thermal Facial Emotion Dataset v2) dataset and evaluated through cross-dataset experiments on the Rainbow subset of the Comprehensive Facial Thermal Dataset (CFTD). The proposed architecture achieved a mean accuracy of 93.8% ± 0.6% (5-fold cross-validation) on KTFEv2 and 84.36% on CFTD Rainbow, with only 1.85 million parameters and 0.68 GFLOPs. These results outperform selected baseline models in terms of both accuracy and computational efficiency. Ablation studies, statistical tests, and explainability analyses confirm the contribution of individual components. The low parameter count suggests potential for edge deployment, though hardware validation remains future work. The proposed architecture offers a promising balance between accuracy and computational efficiency, with the CSAF module and thermal bias providing complementary benefits for thermal emotion recognition.

Keywords: hybrid CNN-ViT, lightweight Vision Transformer, thermal images, multi-scale feature fusion, cross-dataset generalization, computational efficiency, explainability, edge computing

A FINE-TUNED MULTI-AGENT LARGE LANGUAGE MODEL PLATFORM WITH RETRIEVAL-AUGMENTED GENERATION FOR CLINICAL CASE REPORT ANALYSIS

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Abstract: The growing volume of digitised medical case reports, and the need for tools that support their structured analysis, motivated the prototype platform presented in this work. A single general-purpose language model lacks the domain precision and up-to-date references required for reliable case-report analysis; we address this by combining domain fine-tuning with a retrieval-augmented generation (RAG) component that queries a vector database of clinical literature on demand. The platform comprises five specialised agents (general practitioner, surgeon, cardiologist, neurologist and psychologist) and a synthesis agent that consolidates their individual assessments, with each agent reasoning within its specialty and grounded in retrieved medical sources. The shared base model, DeepSeek-R1-Distill-Qwen-7B, was fine-tuned using 4-bit QLoRA on 8,999 chain-of-thought-enriched PubMed case reports (from a curated corpus of 9,999), training 40.4M parameters (0.93% of the model) over three epochs on an A100 GPU. Retrieval draws on 7,679 text chunks extracted from 13 clinical textbooks and guidelines (2,164 pages). On a 501-case held-out test set, the fine-tuned model outperformed the base model across all metrics, reaching ROUGE-1 0.58, BERTScore 0.68, ChrF++ 0.50, faithfulness 0.44 and structural completeness 0.65. These results demonstrate that parameter-efficient domain fine-tuning significantly improves the shared backbone driving all platform agents; end-to-end quantitative evaluation of the retrieval and multi-agent orchestration layers is the subject of ongoing work.

Keywords: large language models, multi-agent systems, retrieval-augmented generation, clinical decision support, parameter-efficient fine-tuning (QLoRA), medical case reports

APPLICATION OF AUTOMATED IMAGE ANALYSIS IN THE BIOINDICATIVE ASSESSMENT OF ACTIVATED SLUDGE PARAMETERS AND THE IMPACT OF TREATMENT PLANTS ON RECEIVING WATERS

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Abstract: The use of a bioindicative analysis method based on community structure indices allows for a quick and cost-effective assessment of activated sludge condition at various stages of biological wastewater treatment, due to the lack of expensive equipment and low environmental impact (no chemical reagents required). It is also useful in assessing the impact of wastewater treatment plants on receiving surface waters. Community structure indices do not require precise identification of organism species; a rapid counting of individuals identified in live specimens within appropriately selected ecological groups is sufficient. These groups differ in their morphological characteristics (visually) and can be observed with a standard transmitted light optical microscope, without the need for preliminary preparation and staining of the specimens. During the analysis of microscopic images, which can be supported by automated image analysis methods using artificial intelligence (e.g., deep learning neural networks), organisms are counted and classified based on visual features that influence their role in the activated sludge ecosystem. This classification significantly simplifies obtaining results for bioindicative assessment, while the use of supporting artificial intelligence models reduces the required time from several hours to a few minutes. Using the software for automated analysis of microscopic images of activated sludge in larger treatment plants can significantly reduce the financial costs of monitoring the stability of biological processes. In smaller treatment plants, which typically lack access to specialized analytical equipment and activated sludge analysis specialists, such software may be the only tool available for monitoring the biological process factor during ongoing operation.

Keywords: automated image analysis, bioindicative assessment, activated sludge parameters, treatment plants, receiving waters

MULTIMODAL AI AND EDGE INTELLIGENCE FOR CONTEXT-AWARE CUSTOMER RELATIONSHIP MANAGEMENT

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Abstract: Contemporary customer relationship management platforms often aggregate heterogeneous operational records without converting them into context-aware, real-time decisions. This paper presents a modular architecture for an artificial-intelligence-enabled CRM system that integrates structured customer and enterprise data with multimodal interaction streams from online channels, virtual assistants, mobile applications, and an IoT concierge terminal. The proposed solution comprises five cooperating layers covering data acquisition, edge concierge processing, integration, analytics, and decision support. At the edge, camera, microphone, and touch events are processed for face localisation and alignment, user identification, and emotion estimation, thereby limiting transmission of raw sensory data and reducing latency. The analytical layer combines CRM and ERP records with text, speech, and visual cues to support intent recognition, customer segmentation, anomaly detection, forecasting, natural-language queries, and recommendation generation. Normalised events are translated into actionable CRM outputs, including personalised offers, follow-up tasks, service alerts, and managerial reports. The prototype demonstrates a deployment approach spanning cloud, on-premises, and embedded components, with perception models trained externally and optimised for execution on accelerators or smart cameras. The architecture addresses interoperability, data protection, network reliability, hosting costs, and human oversight by separating raw perception from business-level decisions. The resulting framework extends CRM from passive data storage to context-aware decision support while retaining human responsibility in complex customer-service scenarios. Future work concerns tighter CRM/ERP integration and further optimisation of the edge inference pipeline.

Keywords: artificial intelligence, customer relationship management, multimodal analysis, edge computing, Internet of Things, virtual assistants, decision support, customer service

CROSS-SIGNER GENERALIZATION OF VISION-LANGUAGE EMBEDDINGS FOR POLISH FINGERSPELLING RECOGNITION

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Abstract: Automatic recognition of fingerspelling sequences is an important component of assistive systems supporting communication with Deaf and hard-of-hearing users. This study evaluates whether sequence-level embeddings generated by the LLaVA-OneVision vision-language model with a Qwen backbone provide discriminative features for Polish Sign Language (PJM) fingerspelling recognition. A publicly available dataset containing 1,659 valid video sequences, 20 gesture classes, and recordings from nine signers was used. Each video was uniformly reduced to at most 30 frames and encoded into a 7,168-dimensional representation. Three embedding variants were compared: mean-pooled hidden states, the last-token representation, and their concatenation. The embeddings were classified using several conventional machine-learning algorithms. A preliminary multimodal variant additionally incorporated textual descriptions derived from detected hand landmarks, but this information did not improve recognition and was omitted from the final pipeline. In standard cross-validation, the Extra Trees classifier achieved the best accuracy, approaching 98%; Decision Tree also performed strongly, whereas Gaussian Naive Bayes and the remaining evaluated methods were less effective. The concatenated embedding provided the most useful feature representation, indicating complementary value from global token-level context and the final hidden-state token. However, signer-independent GroupKFold evaluation with disjoint signer groups produced substantially lower scores, revealing limited generalization across individuals. The results demonstrate the usefulness of vision-language embeddings for PJM fingerspelling recognition while showing that high conventional cross-validation accuracy does not guarantee robustness to unseen signers. Larger and more diverse datasets, improved normalization, and dedicated temporal models are therefore required for reliable deployment.

Keywords: Polish Sign Language, fingerspelling recognition, vision-language model, video embeddings, Extra Trees, signer-independent evaluation

EXPLAINABLE LOCAL EVALUATION OF FACTUAL CONSISTENCY IN AUTOMATED CLINICAL SUMMARIES AGAINST SOAP REFERENCES

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Abstract: Reliable automatic generation of clinical documentation requires more than linguistic fluency because summaries must preserve clinically relevant facts while avoiding unsupported additions. This study presents an interpretable, locally deployable natural language processing pipeline for fact-level evaluation of automatically generated summaries of doctor-patient conversations against references structured according to SOAP. The dataset comprised 500 matched transcript-summary-reference records. Reference elements were available for 500 Subjective, 404 Objective, 316 Assessment, and 496 Plan sections. The hybrid rule-based and factual pipeline validated and normalized inputs, extracted clinical and organizational facts, including symptoms, diagnoses, diagnostic tests, procedures, recommendations, medications, hospitalization, and urgency, and mapped them to SOAP elements while retaining negation, certainty, and temporal context. Summary quality was quantified using element-level accuracy, precision, recall, and F1 score. Stricter case-level accuracy and robustness to 5% token noise were reported as supplementary measures. The method achieved element-level accuracy of 0.9448, precision of 0.9443, recall of 1.0000, and an F1 score of 0.9691. Case-level accuracy was 0.7360, reflecting the more demanding requirement that an entire record be correct. The capped noise-retention score was 1.0000, indicating preserved quality under the applied perturbation. These findings show that automated clinical summaries can be evaluated locally and transparently at the level of clinically meaningful information units. The proposed framework distinguishes omissions from unsupported content and provides an auditable basis for quality assurance. Further validation should incorporate expert review, improved negation handling, synonym mapping, and terminology normalization.

Keywords: clinical summarization, factual consistency, SOAP notes, natural language processing, explainable evaluation, medical documentation

FUZZY LOGIC CONTROLLER FOR AUTONOMOUS OBSTACLE AVOIDANCE IN A QUADROTOR UNMANNED AERIAL VEHICLE

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Abstract: Unmanned aerial vehicles (UAVs), particularly small quadrotor platforms, are increasingly considered for applications in urban environments, including infrastructure inspection, environmental monitoring, and surveillance. One of the main challenges associated with their autonomous operation is the ability to avoid obstacles while maintaining safe and efficient flight. The aim of this study was to develop and evaluate a fuzzy logic-based obstacle avoidance controller for a quadrotor micro aerial vehicle (MAV). The controller was designed using MATLAB and evaluated through computational tests and flight simulation in the Simulink environment. The proposed fuzzy inference system uses three input variables describing the height, width, and depth of an obstacle, and four output variables corresponding to the control signals for the quadrotor motors. Each input variable was described by five fuzzy sets, which formed the basis for the development of fuzzy inference rules. Several defuzzification methods were investigated, including the centroid, bisector, and maximum-based methods. Based on the analysis of the obtained control responses, the centroid method was selected for further evaluation. The developed controller was tested using different obstacle dimensions and subsequently assessed in a 20-second simulated flight scenario involving four obstacles representative of an urban environment. The simulation results demonstrated that the controller generated appropriate motor control responses to the encountered obstacles, enabling the execution of avoidance manoeuvres in the considered scenario. The study indicates the potential of fuzzy logic-based control systems for supporting autonomous obstacle avoidance in small UAVs. Further experimental validation on a physical quadrotor platform is required to assess the performance of the proposed solution under real flight conditions.

Keywords: unmanned aerial vehicle, fuzzy logic controller, autonomous obstacle avoidance, quadrotor, MATLAB/Simulink

AUTOENCODER-BASED REPRESENTATIONS FOR CRIME CLUSTERING

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Abstract: This study investigates the use of autoencoder-based latent representations for clustering crime incidents using a publicly available dataset from Chicago. Data preprocessing included feature extraction, aggregation of selected categorical levels, and the transformation of textual crime attributes into contextual embeddings. Four types of autoencoders – Vanilla, denoising, variational, and convolutional – were evaluated using different architectures and latent-space dimensions. The resulting representations were clustered using k-means, Gaussian mixture models (GMM), and spectral clustering. Clustering results were evaluated using the Adjusted Rand Index (ARI) and Normalized Mutual Information (NMI), measuring agreement with three reference attributes: crime type, detailed crime description, and location description. Vanilla autoencoders combined with k-means and GMM achieved the strongest agreement, particularly for solutions with four or five clusters. The best configuration yielded a mean ARI of 0.53 and a mean NMI of 0.70 for crime type. Comparisons with clustering performed directly on the preprocessed data indicated that selected autoencoder-based representations improved clustering performance. These findings highlight the potential of autoencoders for dimensionality reduction and exploratory crime data analysis, while showing that their usefulness depends on the architecture and clustering method.

Keywords: autoencoders, deep learning, latent representations, clustering, crime data

COMPUTATIONAL FLUID DYNAMICS (CFD)

NUMERICAL CFD ANALYSIS OF CATALYTIC BASKETS IN DUAL-BED CATALYTIC REACTORS

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Abstract: Catalytic baskets used to support catalyst beds can have various designs that direct gas flow in different directions through a catalytic reactor. In industrial practice, axial- and radial-flow reactors are most commonly used. In this study, the influence of tail gas distribution in a dual-bed catalytic reactor on the distribution of linear gas velocity and pressure drop across the catalyst beds was analysed using CFD simulations with ANSYS FLUENT. The results of experimental studies and literature data indicate a significant effect of linear gas velocity in the catalyst bed on its performance efficiency. CFD numerical calculations were carried out for a model SCR-deNOx/LT-deN_2O reactor used in the pilot nitric acid plant at Łukasiewicz – INS, for different catalytic basket designs. For each basket design, identical boundary conditions and operating parameters of the SCR reactor were assumed. The calculation results demonstrated a significant influence of the catalytic basket design on the distribution of linear gas velocity and gas pressure drops in a dual-bed catalytic system. The most favourable solution proved to be a coaxial arrangement of the catalyst beds in the reactor, without separating them by a space. The lowest values of linear gas velocity and flow resistance through the system of two catalyst beds were obtained for the axial-radial catalytic basket design, which ensures contact between the two catalyst beds through a porous partition.

Keywords: CFD, catalytic baskets, dual-bed catalytic reactors

CFD-BASED ANALYSIS OF LIFT AND DRAG CHARACTERISTICS OF A UAV SEAPLANE IN TRANSITIONAL FLOW REGIMES

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Abstract: This study presents a computational investigation of the aerodynamic performance of a small-scale unmanned aerial vehicle (UAV) configured as a seaplane operating in transitional flow regimes. The analysis focuses on the prediction of lift and drag characteristics at low Reynolds numbers representative of typical UAV flight conditions. A three-dimensional model of the seaplane, including wing, fuselage, and float assemblies, was developed and analyzed using Reynolds-Averaged Navier–Stokes (RANS) equations coupled with a transition-sensitive turbulence model. Numerical simulations were conducted over a range of angles of attack and freestream velocities to capture the onset and development of laminar–turbulent transition. Special attention was given to the aerodynamic interaction between the wing and floats, which significantly influences flow separation and drag penalties. Grid independence studies and validation against available experimental or empirical data were performed to ensure numerical accuracy. The results indicate that transitional effects play a critical role in determining aerodynamic efficiency, particularly in the pre-stall region. The presence of floats increases parasitic drag while also modifying the lift curve slope due to interference effects. The findings provide insight into the optimization of UAV seaplane configurations and highlight the importance of incorporating transition modeling in low Reynolds number aerodynamic analyses.

Keywords: CFD, UAV, seaplane, Ansys, RANS

DESIGN AND EXPERIMENTAL VALIDATION OF A PROPELLER FOR AN UNMANNED AERIAL VEHICLE WITH MTOW UP TO 25 KG

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Abstract: This paper presents the design, manufacturing, and experimental validation of a propeller intended for an unmanned aerial vehicle (UAV) with a maximum take-off weight (MTOW) of up to 25 kg. The primary objective of the study was to develop a propeller geometry capable of delivering the required thrust characteristics at maximum rotational speed and to evaluate the agreement between computational predictions and experimental measurements. The design process was based on a proprietary computational algorithm, which enabled the determination of key geometric parameters of the propeller using propulsion system characteristics and predefined operating conditions. A two-bladed propeller with a diameter of 25 inches and fixed pitch was designed. Based on the obtained parameters, a detailed geometric model was developed, followed by the fabrication of a composite prototype. Experimental investigations were conducted using a dedicated test stand, where static thrust, torque, and selected operational parameters were measured. The obtained results enabled the assessment of the consistency between numerical predictions and experimental data, as well as the evaluation of the accuracy of the proposed design methodology. The developed approach, supported by experimental validation, contributes to the advancement of computational tools for rapid propeller selection and design in light UAV applications.

Keywords: CFD, UAV, Composite propeller, CAD, CAM

MODELING AND ANALYSIS OF WING ICING ON A BOEING 737-800 AIRCRAFT USING ANSYS

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Abstract: This paper presents a numerical analysis of the icing process on the wing of a Boeing 737-800 aircraft and its impact on aerodynamic characteristics. A geometric model of a wing section was developed using a quasi-3D (2.5D) approach, followed by simulations of airflow and ice accretion using Computational Fluid Dynamics (CFD) methods in the ANSYS environment, including the FENSAP-ICE module. The analyses were performed under conditions corresponding to real cruise flight, with a freestream velocity of 216 m/s and an ambient temperature of −20°C. Two icing durations were considered: 300 s and 3000 s. In the case of short ice accretion time, the impact on aerodynamic performance was relatively minor, despite the presence of a noticeable ice mass. However, for the longer duration (3000 s), a significant ice layer accumulation (approximately 161 kg) was observed, leading to changes in airfoil geometry, increased surface roughness, and flow disturbances. The results demonstrated a substantial increase in drag coefficient and a reduction in lift generation efficiency. Icing was found to promote earlier flow separation, deterioration of aerodynamic efficiency, and a reduction in the safe operational envelope of the wing. The conducted study confirms the significant influence of icing on flight safety and aircraft performance characteristics.

Keywords: aircraft icing, ice accretion, aerodynamic performance, CFD simulation; ANSYS, FENSAP-ICE

CFD INVESTIGATION OF THERMAL MIXING ENHANCEMENT OF SHEAR-THINNING FLUIDS IN SHORT PASSIVE TLCCM MICROMIXERS

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Abstract: Thermal mixing in chaotic microdevices holds significant promise across a wide range of applications, particularly in thermal engineering. Among microfluidic systems, the Two-Layer Crossing Channels Micromixer (TLCCM) has demonstrated notable effectiveness in thermal mixing of Newtonian fluids, which motivated the present study to examine its behavior with pseudoplastic fluids. A numerical comparative analysis was conducted to evaluate the thermal mixing performance of shear-thinning fluid flows across three TLCCM configurations: TLCCM-X, TLCCM-KX, and TLCCM-O. The governing equations, including Navier-Stokes, mass conservation, energy, and species transport, were solved numerically using a CFD code. The pseudoplastic fluids considered are carboxymethyl cellulose (CMC) solutions, modeled using the power-law approach, with flow behavior indices spanning from 0.49 to 1 and generalized Reynolds numbers ranging from 0.2 to 70. The setup involves injecting a hot fluid at 330 K and a cold fluid at 300 K through two distinct inlets of each micromixer. The study aims to provide both quantitative and qualitative insight into the combined influence of fluid rheology and Reynolds number on thermal mixing performance. A comparative assessment is also presented to identify which configuration achieves the highest mixing efficiency, with the probability density function (PDF%) evaluated at the outlet serving as the key indicator of thermal homogenization quality.

Keywords: CFD, TLCCM micromixer, pseudoplastic fluids, thermal mixing degree, probability density function

COMPARATIVE ANALYSIS OF PASSIVE PLANAR MICROMIXERS FOR NEWTONIAN AND NON-NEWTONIAN FLUID MIXING: A NUMERICAL STUDY

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Abstract: This study presents a numerical investigation of mixing performance in passive planar micromixers, with a focus on the flow behavior of both Newtonian and non-Newtonian fluids. The primary aim is to assess how channel geometry and flow conditions influence mixing efficiency through computational modeling using ANSYS Fluent 16.0. Three geometrically distinct passive micromixers: M1, M2, and M3 were designed and systematically evaluated based on key performance metrics, including mixing degree, pressure drop, mixing energy cost, residence time, and thermal mixing degree. The findings revealed that the M2 and M3 configurations surpassed the M1 design in mixing quality, particularly at elevated Reynolds numbers. While the M3 micromixer yielded the highest mixing degree, it incurred substantially greater pressure drops and energy consumption. In contrast, the M2 micromixer offered a favorable trade-off among mixing performance, energy efficiency, and residence time. A dedicated analysis of non-Newtonian fluid mixing was further conducted using the M2 micromixer, demonstrating its notable hydrodynamic efficiency. Two power-law indices were considered: n = 0.49 and n = 0.75. Results indicated that the fluid with near-Newtonian behavior (n = 0.75) reached a high mixing degree more rapidly, whereas the highly viscous fluid (n = 0.49) exhibited consistently poor mixing even at increased flow velocities. These findings underscore the critical role of geometric design and fluid rheology in optimizing mixing performance within microfluidic systems.

Keywords: CFD, Mixing degree, Mixing energy cost, Residence time, Pressure loss, Chaotic advection, Non-Newtonian fluid

CFD MODELING OF WATER AEROSOL FLOW IN AN ICING WIND TUNNEL

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Abstract: The present study concerns the numerical modeling of water aerosol flow in a subsonic wind tunnel adapted for icing studies. The work focuses on the numerical representation of aerosol flow generated by injector system, with particular attention paid to modeling assumptions, injection parameters, and behavior of the dispersed phase within the wind tunnel test section. The aim of the study is to develop a numerical model for determining aerosol flow parameters. In combination with experimental results, the theoretically determined characteristics may be used to assess the fidelity of reproducing atmospheric conditions conducive to icing in both model-scale experiments and CFD simulations. In the numerical model, gas phase was represented by air, while the dispersed phase consisted of water droplets introduced into the flow by means of injector system. The motion of the liquid-phase particles was described using the Discrete Phase Model, commonly applied in droplet transport analyses. The droplet diameter distribution was modeled using the Rosin–Rammler distribution. The model included wind tunnel geometry as well as the arrangement and shape of the injectors. The numerical analysis covered droplet motion in the air stream, influence of droplet diameter distribution on the dispersed-phase structure, and the formation of the aerosol field in the measurement region. The spatial distribution of the liquid phase was also evaluated, since aerosol-field non-uniformity affects the quality of icing-condition reproduction. The CFD modeling results made it possible to assess the suitability of Ansys Fluent for analyzing two-phase flow structures in a wind tunnel. The analysis indicates that the DPM model can support the assessment and calibration of water-injection systems used in icing wind tunnels. The results also confirm that injection parameters, droplet size distribution, and boundary conditions significantly influence the predicted granulometric parameters, such as MVD (Mean Volume Diameter), LWC (Liquid Water Content), and the spatial distribution of the aerosol.

Keywords: Computational Fluid Dynamics (CFD), Ansys Fluent, multiphase flow, water aerosol flow, Discrete Phase Model (DPM), Rosin–Rammler distribution, droplet size distribution, icing wind tunnel

NUMERICAL INVESTIGATION OF THE AERODYNAMIC CHARACTERISTICS OF THE LUBLIN R-XIIID AIRCRAFT

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Abstract: The reconstruction of historical aircraft requires not only an accurate reproduction of their geometry and structural configuration, but also a reliable assessment of their aerodynamic behaviour. In the case of the Lublin R-XIIID aircraft, the limited availability of complete aerodynamic documentation makes numerical modelling an important tool for recovering information on its original flight characteristics and for supporting subsequent experimental investigations. The aim of the present study was to determine the basic aerodynamic characteristics of the reconstructed Lublin R-XIIID aircraft using Computational Fluid Dynamics (CFD). A detailed three-dimensional CAD model of the aircraft was developed on the basis of available geometric and archival data and subsequently adapted for numerical analysis. Particular attention was paid to preserving the main aerodynamic features of the original configuration while ensuring appropriate computational quality of the model. The numerical simulations were carried out using ANSYS Fluent. A computational domain was developed and several meshes with different levels of refinement were generated. Prior to the final calculations, a grid-independence study was performed to assess the sensitivity of the aerodynamic results to spatial discretisation and to select a mesh providing an appropriate compromise between numerical accuracy and computational cost. The CFD analysis enabled the determination of the principal aerodynamic coefficients, including the lift coefficient, drag coefficient and pitching moment coefficient, as well as their variation with the selected flow conditions. The pressure and velocity fields around the aircraft were also analysed in order to identify characteristic flow structures and regions significantly affecting the aerodynamic behaviour of the configuration. The obtained results constitute an important stage in the reconstruction and aerodynamic assessment of the Lublin R-XIIID aircraft. The numerical model provides a basis for further comparison with wind-tunnel measurements and for the validation of the reconstructed aerodynamic characteristics. Such an approach contributes to preserving not only the geometric form of a historically significant aircraft, but also knowledge of its aerodynamic properties and operational behaviour.

Keywords: Lublin R-XIIID, computational fluid dynamics, CFD, ANSYS Fluent, aerodynamic characteristics, mesh independence, historical aircraft reconstruction

COMPUTER SIMULATIONS OF PROCESSES AND PHENOMENA

MACHINE LEARNING-BASED PREDICTION OF AERODYNAMIC CHARACTERISTICS OF AN ELECTRIC UAV PROPULSION SYSTEM

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Abstract: This study investigates the application of machine learning techniques for the prediction of aerodynamic characteristics of an electric UAV prop. system. The research included experimental propeller tests in a wind tunnel and the development of three models: a classical multilayer perceptron (MLP), a deep neural network and dropout (DNN with BN/Dropout), and a Random Forest-based model. The models were trained on data including rotational speed, airflow velocity, and the advance ratio. The objective of the modeling was to predict thrust, torque, and efficiency. The quality of the models was assessed using MSE, MAE, RMSE, and the coefficient of determination R^2, together with residual distribution analysis, autocorrelation functions (ACF/PACF), and linear regression with confidence intervals. The analysis of residuals and ACF/PACF functions revealed a random error character in the MLP model and the presence of systematic structures in the Random Forest model. The highest accuracy was achieved for the classical MLP network, which attained $R^2 \approx 0.98$ for both thrust and torque. The Random Forest model was characterized by a markedly greater error dispersion, especially for thrust (MAE = 2.306 N). The regularized DNN network exhibited intermediate performance, achieving its best fit for torque ($R^2 = 0.931$). A residual analysis verified the random error pattern in the MLP model and systematic structures in the RF model. Prediction of the dimensionless thrust and power coefficients C_T and C_P resulted in the lowest mean errors for the MLP model (MAE C_T = 6.35%, MAE C_P = 4.96%), while the RF method generated maximum errors of up to 38% for C_T and 24.5% for C_P. The results confirm that a classical neural network represents a reliable and robust tool for predictive modeling of aerodynamic parameters of an electric propeller propulsion system. It ensures acceptable systematic errors.

Keywords: Machine-learning, UAV, propeller, thrust, power

ANALYSIS OF FACTORS AFFECTING PRODUCT PRICE MARGINS IN THE DISTRIBUTION CHAIN

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Abstract: The objective of this article is to examine the impact of product characteristics (product category, package size) and the supplier on the percentage price margin in the alcoholic beverage distribution chain, as well as to assess the usefulness of machine learning models in predicting high margins. The analysis was conducted in the R environment on a dataset of 12,260 observations. One-way analysis of variance (ANOVA) with Tukey's post-hoc test and the nonparametric Kruskal-Wallis test were used to test the research hypotheses. Two classification models were built to predict high margins: logistic regression and a CART decision tree (75/25 data split), which were evaluated using AUC, balanced accuracy, and the DeLong test. The average percentage margin in the dataset was 52.78%. The analyses confirmed a significant effect of product classification (ANOVA $F = 1932.32$; $p < 0.001$; wine 58.96% vs. spirits 37.72%), package size (ANOVA $F = 37.10$; $p < 0.001$), and supplier (Kruskal-Wallis $\chi^2 = 3100.97$; $p < 0.001$) on the margin. Logistic regression achieved an AUC of 0.9388, while the decision tree achieved an AUC of 0.9079 and a higher balanced accuracy (0.8930 vs. 0.8811), indicating purchase price as the main determinant of high margin. The results indicate that the wine category and the appropriate selection of suppliers are key factors in optimizing a distributor's profitability. Decision trees eliminate the "black box" problem by generating understandable and easy-to-implement business decision rules that support product assortment management and pricing policy.

Keywords: margin prediction, CART classification, logistic regression, decision support systems, product assortment analysis, model interpretability

RESILIENCE ANALYSIS OF A WATER DISTRIBUTION NETWORK UNDER FAILURE SCENARIOS IN THE AQUARDIS VIRTUAL CITY

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Abstract: The data of real water distribution networks are considered sensitive, as water supply systems constitute critical infrastructure. For research purposes, quasi-real networks located in so-called virtual cities are gaining increasing popularity. Virtual cities are publicly available spatial datasets that describe the geographical structure, technical infrastructure, and demographic characteristics of a hypothetical settlement. This paper presents a resilience analysis of a water distribution system in the proprietary virtual city AquaRDIS (Aqua Research and Design for Infrastructure Sustainability) under a range of failure scenarios. The aim of the study is to evaluate the network's ability to maintain service continuity and an acceptable level of performance in the face of disruptions such as pipe failures, increased water demand for firefighting, and water contamination incidents. A simulation-based approach was employed, combining hydraulic modelling with a set of resilience indicators, including, among others, continuity of water supply and the stability of hydraulic operating conditions. Various configurations of adverse events, differing in complexity, were analysed. The results indicate that the network's topological structure and the redundancy of key components play a crucial role in mitigating the impacts of disruptions. Vulnerable areas of the system were also identified, and their targeted modernization could significantly enhance the overall resilience of the network.

Keywords: water distribution network, resilience analysis, virtual city, AquaRDIS, failure scenarios, hydraulic modelling

ULTRA-WIDEBAND-BASED VELOCITY ESTIMATION WITH KALMAN FILTERING FOR FOLLOW-ME UNMANNED GROUND VEHICLE APPLICATIONS

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Abstract: Ultra Wideband (UWB) technology is a wireless radio communication technology used, among others, in location systems. This paper presents an experimental study on velocity estimation for Unmanned Ground Vehicles (UGVs) operating in a follow-me scenario using Ultra-Wideband technology. In follow-me applications, UGV is required to continuously track and follow a moving guide. The proposed approach utilizes Two Way Ranging (TWR) distance measurements from UWB modules to derive velocity estimates of the tracked object. All signal processing and estimation algorithms were developed and validated in the MATLAB software. Experimental tests were conducted outdoor using a dedicated MDEK TREK1000 hardware, and the results were compared against reference measurements using GNSS with RTK to assess estimation accuracy. The article evaluates the obtained results in terms of their applicability to a follow-me system.

Funding: This work was financed by the Military University of Technology under research project UGB 22-104/2026 (531-000104-W100-22).

Keywords: Ultra-Wideband, velocity estimation, Unmanned Ground Vehicle, UGV, follow-me system, signal filtering, Matlab

APPARATUS FOR FIELD TESTING AND VALIDATION OF NUMERICAL MODELS OF MINE-SOIL INTERACTION UNDER WHEEL OR TRACK PRESSURE

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Abstract: This paper presents the design, implementation and application of a dedicated experimental test rig developed for the validation of numerical models describing the interaction between vehicle running gear (wheel or track) or a demining roller, and anti-tank mine embedded in deformable soil. The proposed measurement system represents a realistic physical simulator of an anti-tank mine, reproducing the geometry and functional characteristics of real devices. It enables simultaneous measurements of the vertical displacement of the embedded object relative to the surrounding soil and the contact load applied by a wheel or a track system acting on the pressure plate of the mine's fuse. The presented apparatus allows investigation of the influence of contact area on load transfer mechanisms and soil deformation response. This paper describes a series of tests conducted using the described apparatus in conditions representative of a soil with reduced bearing capacity, where excessive settlement and load redistribution significantly affect the interaction process. Preliminary experimental results obtained for both wheeled and tracked running gears indicate that the developed apparatus and measurement methodology provide a consistent experimental basis for calibration of constitutive models and validation of advanced numerical approaches, including finite element, discrete element, or multibody dynamics methods.

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Keywords: mine-soil interaction, model validation

IDENTIFICATION OF EQUIVALENT STIFFNESS REPRESENTATION IN A SIMULATION MODEL OF A RIBBON PONTOON BRIDGE

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Abstract: The focus of the study is identification of the structure's longitudinal stiffness and its implementation into the kinematic constraints of the simulation model. The main objective was to achieve a high-fidelity representation of the actual behaviour of connections between pontoon blocks by accounting for both their angular compliance and joint clearance. The model parameters, including the flexural stiffness of a pontoon block, the angular stiffness of block connections, and the limiting hinge-locking angle, were determined from an analysis of experimental results obtained on a full-scale structure. The flexural stiffness of an individual pontoon was identified based on static deflection measurements. The angular stiffness of pontoon connections was determined using experimental data obtained from tests on coupled pontoon segments, with separation of deformation contributions from both the load-bearing structure and the joint components. These parameters were subsequently implemented in a numerical model of the bridge under static loading conditions on a water obstacle. The model was then calibrated by minimizing discrepancies between numerical predictions and experimental results, enabling the identification of the limiting locking angle of the connections. Model accuracy was assessed by comparing vertical displacements of characteristic points obtained in simulations and experiments. The results confirmed that the adopted modelling approach, incorporating the identified equivalent stiffness and joint-clearance parameters, accurately reproduced the experimental bridge response for the analysed static calibration case.

Funding: This work was financed by the Military University of Technology under research project UGB 22-104/2026 (531-000104-W100-22).

Keywords: pontoon bridge, longitudinal stiffness, numerical model, multibody system

THE USE OF DIGITAL VOLUME CORRELATION WITH COMPUTED TOMOGRAPHY TO ANALYZE DISPLACEMENT AND WALL THICKNESS OF MULTI-OPERATIONAL PRESSING OF CYLINDRICAL ALUMINUM EXTRUSIONS

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Abstract: This paper presents the possibility of using computed tomography to determine displacements and stresses during controlled deformation. Tomographic examinations are most often used to assess the quality of castings, welded joints, 3D prints, and electronic systems. These non-destructive tests enable spatial imaging of even the smallest changes in the material, such as cracks, porosity, inclusions, and many other imperfections. Dedicated programs enable precise qualitative analysis, including analysis of porosity, inclusions of other materials, material division, creation of a digital twin, and other advanced options such as digital volume correlation or analysis of the state of displacements and stresses. The Digital Volume Correlation tool allows for the comparison of components in two states before and after deformation. The tests were conducted on aluminum samples. The samples were first extruded and then re-extruded in the next three stages. Single-voxel displacement tracking was used to determine the displacements and von Mises strain in the material. VG Studio software allows for visual representation of displacement and stress. The data obtained also enabled analysis of the thickness of the wall after deformation. The research results indicate that tomographic examinations and Digital Volume Correlation (DVC) assessment can be successfully used to monitor the condition of devices and structures. The scientific aim of the article is to reveal the magnitude of changes in material displacement in extruded elements and compare them with the change in the height of the extrudates. Moreover, the work aims to show changes in the wall thickness of the extrudates throughout their volume and to compare the results of CT tests with measurements using classical methods.

Keywords: computed tomography, Digital Volume Correlation, drawing, material deformation, wall thickness

STUDY OF THE INFLUENCE OF ESD PROCESS PARAMETERS AND A COMPARATIVE ANALYSIS OF MICROSCOPY AND COMPUTED TOMOGRAPHY IN THE QUALITATIVE ASSESSMENT OF COPPER COATINGS ON AN ALUMINIUM SUBSTRATE

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Abstract: This article presents research into surface coatings produced by the electro-spark deposition (ESD) method on aluminium using a copper electrode. ESD is a surface modification technique that uses short current pulses (electrical discharges) to transfer material from the working electrode (anode) to the workpiece (cathode). The evaluation involved observing the effect of voltage and capacitor capacitance during the ESD process on the thickness of the ESD coating. To minimise the number of experiments required, a two-factor, five-level Hartley experimental design was selected. The study demonstrates the potential use of computed tomography to monitor the condition of the resulting ESD coating. VG Studio software enables visualisation of the resulting ESD coating, including measurement of its thickness or volume. Microscopic observations were then carried out on the prepared samples to analyse the thickness and structure of the coatings. The use of tomographic studies in the analysis of ESD coatings ensures significantly greater representativeness of the results compared to traditional microscopy. It allows for a spatial assessment of the coating's continuity, which eliminates the risk of misinterpreting quality based on individual cross-sections. Furthermore, the spatial data obtained from the basis for precise mathematical models, enabling a better understanding of the process's energy balance and more accurate prediction of ESD coating thickness as a function of process parameters.

Keywords: electro-spark deposition, computed tomography, microscopic examination, coatings

ENTROPY-BASED INDICES IN ECONOMIC AND SOCIAL RESEARCH

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Abstract: Entropy-based indices, rooted in Shannon's information theory, have proven their value in the natural sciences as robust measures of diversity and structural complexity. However, their application in economics and the broader social sciences remains underexplored, despite considerable methodological potential. This article examined the possible ways of employing entropy-based indices, particularly the Shannon index and the related Theil index in economic and social research, and discussed the analytical gains such applications may offer. The paper reviewed existing cases where entropy measures have already found economic use: as indicators of sectoral diversification of regional and national economies, as measures of income inequality and distributional uncertainty, and as tools for assessing country competitiveness and export specialization in international trade. Building on these precedents, the elaboration advanced the argument that entropy-based indices could substantially enrich analyses in the tradition of Thomas Piketty's Capital in the Twenty-First Century (2013). Where Piketty relied primarily on aggregate wealth-to-income ratios and income shares of top deciles, entropy measures allow for a more granular decomposition of distributional structures across sectors, time periods, and countries. Applied to the data on the distribution of employment and GDP across economic sectors, the Shannon index reveals the patterns of structural convergence or divergence that conventional metrics may obscure. The work concluded that entropy-based indices constitute a promising and accessible complement to established social science tools, capable of capturing distributional complexity at multiple scales.

Keywords: Shannon entropy, entropy-based indices, Theil index, economic diversity, income inequality, structural change, sectoral analysis, information theory, social sciences

ANALYSIS OF MULTIDIMENSIONAL DATA CONTAINING PRECIPITATION VARIABILITY AND THE PRESENCE OF MICROORGANISMS IN THE BYSTRZYCA RIVER FOR ENVIRONMENTAL MONITORING PURPOSES

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Abstract: The rapid growth of urban areas, industry, and agricultural activities contributes to increasing pressure on aquatic ecosystems. One of the key factors affecting surface water quality is precipitation, which can cause pollutants to be washed off from catchment areas and transported into rivers. Variability in precipitation, including both dry periods and heavy rainfall events, may influence environmental conditions and the abundance of microorganisms in flowing water bodies. The aim of this study was to analyze the relationship between precipitation variability and the occurrence of periphytic microorganisms in the Bystrzyca River in the Lublin area. The research material consisted of samples collected at selected monitoring sites located along the studied section of the river. Data on microorganism abundance were compared with precipitation records from a weather station located within the catchment area from which rainwater is drained into the stormwater system and subsequently discharged into the Bystrzyca River. Particular attention was paid to determining the correlation between precipitation intensity and the abundance of individual microorganism species. The analysis made it possible to assess the impact of precipitation variability over time on changes in the quantitative characteristics of periphytic algal communities in the Bystrzyca River. The results may support surface water quality monitoring and help identify periods and areas particularly vulnerable to deterioration in ecological status. The data were analysed using entropy-based indices derived from information theory (e.g. the Shannon Index) by R statistical programming language (RStudio), which made it possible to assess both diversity and the structural balance of the communities.

Keywords: Multidimensional data, precipitation variability, peryphyton, green algae

RECOGNIZING TESTACEA USING AUTOMATIC IMAGE ANALYSIS ALGORITHMS – EUGLYPHA AS AN EXAMPLE

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Abstract: Single-celled eukaryotes from the Euglyphae family are a bioindicator in activated sludge wastewater treatment. Their condition can help determine the quality of the entire ecosystem responsible for the process, as well as detect irregularities and predict impending failure. This work focused on the application of various versions of the automatic image recognition algorithm (YOLO) to recognise Euglypha organisms obtained using a microscope, and the robustness of the algorithm to human errors made during image preparation using a previously trained algorithm. Particular emphasis was placed on changes in individual versions of the algorithm that have emerged with technological advancements and the requirements resulting from the recognition of specific types of objects.

Keywords: image analysis, object localisation and recognition, machine learning, Euglypha, activated sludge, treatment plant

GIS-BASED AUTOMATION OF INPUT DATA PREPARATION FOR HYDRODYNAMIC STORMWATER SYSTEM MODELING

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Abstract: The study proposes a methodology for automating the preparation of a hydrodynamic stormwater sewer network model using a GIS environment. The developed algorithm employs QGIS tools to automatically determine and assign the parameters required for individual model elements. The greatest benefit of the proposed automation was achieved in generating the parameters that are not directly available in the source data, but are derived from object geometry and spatial relationships. The final stage of the developed algorithm consisted of generating an SWMM input file using a dedicated QGIS plugin. The proposed methodology was applied to develop a hydrodynamic model of a selected section of the stormwater network in Lublin. The simulation results were used to evaluate the hydraulic performance of the stormwater network in terms of pavement maintenance and road traffic safety, as well as to develop an operational risk classification supporting the planning of monitoring, maintenance, and rehabilitation of the stormwater system infrastructure.

Keywords: Geographic Information System, QGIS, SWMM, hydrodynamic modeling, input data preparation, pavement maintenance, road traffic safety

THE USE OF SELECTED DEEP LEARNING METHODS FOR THE DETECTION AND CLASSIFICATION OF BIOLOGICAL OBJECTS ON DIGITAL IMAGES

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Abstract: This study investigated the use of selected deep learning methods for the detection and classification of biological objects – testate amoebae, which play a significant role in the bioindication process due to their sensitivity to environmental changes in water quality. Traditional detection of such organisms is time-, work-, and cost-intensive, as it requires an analysis to be carried out by a qualified specialist. Consequently, the use of deep learning models for this purpose makes it possible to speed up the selected species identification process during bioindication assessment of technological lines of treatment or evaluation of natural environment quality. The data used in this study were prepared using a transmitted light microscope in bright field observation mode coupled with a digital camera mounted on the third optical line. Collected environmental samples were divided into three separate sets for model training, validation, and testing. The approach to training included fine-tuning and the use of adjusted hyperparameters for the target dataset. The architectures were evaluated and compared based on their effectiveness in detecting the testate amoebas. The comparison was made on the basis of standard metrics specified for assessing models' quality of detection, sensitivity, specificity, and accuracy of predictions.

Keywords: deep learning methods, detection and classification of objects, automatic analysis of digital images, testate amoebae

STABLE CLASS-CONDITIONED QUANTISED VAE FOR SYNTHETIC LUNG DISEASE VOLUMES

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Abstract: This study evaluates autoencoder (AE), variational autoencoder (VAE), and class-conditioned quantised variational autoencoder (QVAE) architectures for controllable generation of synthetic lung-disease volumes. Data were produced by a numerical physiological model as 128 × 128 × 128 voxel grids; each case was described by up to 22 parameters and assigned to one of seven categories spanning healthy lungs and six respiratory conditions. The QVAE uses nearest-codebook quantisation, a straight-through estimator, exponential-moving-average codebook updates, and affine latent modulation from learned class embeddings. To counter instability at higher latent dimensions, training combines Group Normalisation, LeakyReLU, variance safeguards, automatic mixed precision with gradient scaling, gradient clipping, KL annealing, VQ-loss warmup, AdamW optimisation, adaptive learning-rate reduction, and early stopping. Comparison shows that the AE reconstructs efficiently but cannot support reliable latent sampling, while the VAE yields smoother interpolation but limited discrete semantic control. At z = 512, the QVAE converged stably. Despite transient KL-term growth, reconstruction loss stabilised and decreased after annealing, no NaN excursions were observed, and class conditioning enabled disease-guided synthesis. These results demonstrate that controllable volumetric generation depends jointly on structured latent coding, sufficient representational capacity, and explicit numerical-stability engineering. The framework supports targeted synthesis and future augmentation of synthetic lung-imaging datasets, and motivates ablation studies of loss weighting and codebook utilisation.

Keywords: quantised variational autoencoder, class-conditioned generation, lung disease imaging, synthetic volumetric data, vector quantisation, numerical stability

AOA SENSORS AND CLUSTER TRIANGULATION FOR 3D INDOOR LOCALIZATION

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Abstract: This study presents a simulation framework for tracking a moving transmitter in three-dimensional indoor space by combining multi-anchor angle-of-arrival (AoA) sensing with spatial triangulation. Ceiling-mounted anchors are represented by eight-element antenna arrays. For each trajectory sample, the model generates IQ observations from the transmitter-to-array geometry and independently estimates azimuth and elevation at every anchor using the Multiple Signal Classification (MUSIC) algorithm. Parabolic interpolation of the MUSIC pseudospectrum refines the directional estimate beyond the angular scan-grid resolution. Pairwise anchor rays then produce candidate positions. To limit the influence of inconsistent intersections, the solution identifies the dominant group using DBSCAN, averages its points, and applies a median-based fallback when triangulation is unstable or data are sparse. Simulations reproduce horizontal motion together with small height variations and compare configurations with three, four, and five anchors. The mean localization errors were 56.576 cm, 41.194 cm, and 2.573 cm, respectively. The results show that increased measurement redundancy can substantially improve both localization accuracy and robustness to individual AoA errors, although performance remains dependent on anchor geometry and angular-estimation quality. Under the analyzed scenario, the five-anchor configuration achieved centimeter-level accuracy. The framework provides a reproducible basis for studying error propagation, optimizing anchor deployment, and developing resilient indoor localization systems before hardware implementation.

Keywords: three-dimensional indoor localization, angle of arrival, music algorithm, antenna arrays, spatial triangulation, DBSCAN clustering, moving-object tracking, localization error

MONTE CARLO MODELLING OF LIGHT TRANSPORT FOR OPTICAL TOMOGRAPHY IN HETEROGENEOUS MEDIA

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Abstract: This paper presents a Monte Carlo framework for simulating photon transport in heterogeneous absorbing and scattering media as a simplified forward model for optical tomography. The method tracks individual photons through spatial maps of the absorption coefficient, scattering coefficient, and local light-propagation velocity, thereby allowing inclusions with optical properties different from the background to be represented. Photons are initialized at the boundary of the computational domain and propagated iteratively. At each step, survival is governed by exp[-(α + σ)Δs], whereas scattering events and changes in direction are sampled stochastically. Photons reaching the detector are counted and removed, and a density map of visited grid points is accumulated to characterize transport paths. The implementation supports both CPU and GPU execution. In an illustrative experiment, 20,000 photons were launched into a medium containing a spherical inclusion. The background coefficients were α = 0.02 m^-1 and σ = 0.005 m^-1, while both coefficients within the inclusion were set to 0.1 m^-1. The inclusion produced marked changes in the spatial distribution of photons and in detector statistics, with 8,776 photons ultimately registered. The results confirm that the model captures the influence of localized optical heterogeneity on photon propagation and detection. The proposed framework can support synthetic-data generation, detector-configuration studies, and subsequent development of reconstruction algorithms for optical tomography.

Keywords: Monte Carlo simulation, photon transport, optical tomography, heterogeneous media, optical absorption, multiple scattering, GPU computing

FINITE ELEMENT METHOD (FEM)

THE EFFECT OF TRANSITION RADIUS ON DRY ICE FLOW AND BOUNDARY FORCE DURING THE EXTRUSION PROCESS: AN ANALYTICAL-NUMERICAL-EXPERIMENTAL STUDY

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Abstract: The study examines the influence of the transition radius on dry ice flow behavior and boundary extrusion force in the compaction–extrusion process using single-channel conical–cylindrical dies. An original analytical model is proposed to describe the relationship between die geometry and material flow kinematics, with particular emphasis on the role of the convex transition radius in shaping velocity value and force conditions within the die channel. The analytical predictions are validated through numerical simulations and experimental investigations. Numerical analyses are conducted using the Drucker–Prager Cap model combined with the Smoothed Particle Hydrodynamics method to capture the compressible behavior of dry ice and large deformation flow in the transition region. Experimental tests are performed using a dedicated test rig, and the results are evaluated statistically to ensure reliability. The results demonstrate that increasing the transition radius improves flow uniformity and reduces stress concentrations. Good agreement between analytical, numerical, and experimental results confirms the validity of the proposed approach. The developed framework provides a physically consistent basis for the design and optimization of extrusion dies, thereby improving process efficiency and enhancing tool durability in dry ice pellet production.

Keywords: dry ice extrusion, extrusion velocity, limit extrusion force, transition section geometry, energy consumption

COMPOSITE FOAM BASED SANDWICH STRUCTURE SUBJECTED TO LOW-VELOCITY IMPACT

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Abstract: This study presents an experimental-numerical investigation of the low-velocity impact (LVI) response of composite sandwich structures incorporating a metal-ceramic foam core and carbon fiber reinforced polymer (CFRP) face sheets with different stacking sequences. The primary objective is to evaluate the influence of fiber architecture on damage initiation, propagation mechanisms, and overall impact resistance. LVI tests were conducted under controlled energy levels, enabling quantitative assessment of force-displacement response, energy absorption, and peak load characteristics. The experimental campaign was complemented by finite element simulations developed in an explicit dynamic framework. The numerical model incorporates advanced material descriptions, including strain-rate sensitive plasticity for metallic constituents, Hashin-based damage criteria for composite plies, and cohesive zone modeling for interfacial debonding. The results demonstrate that the stacking sequence of CFRP layers significantly affects both the damage tolerance and energy absorption capability of the sandwich structure. Hybrid configurations exhibit improved impact performance, characterized by delayed damage initiation and enhanced dissipation of impact energy.

Keywords: fiber composite, metal-ceramic foam, low-velocity impact, damage analysis, finite element method

MODEL SIMPLIFICATIONS INFLUENCE ON A SMALL-CALIBRE PROJECTILE ARMOUR PENETRATION SIMULATIONS RESULTS

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Abstract: This paper presents an analysis of the perforation process of a steel armor plate by a small-caliber projectile using the finite element method (FEM) in a dynamic approach. The study aimed to determine the impact of simplifications in the numerical modeling of the projectile on the obtained results and to verify these through experimental field tests. The research involved simulations employing various projectile models: perfectly rigid, elastic, plastic, and plastic with a failure criterion. The simulation results were compared with actual values of projectile velocity after perforating a 1.3964 steel sample and with the morphology of deformations. It was found that including the plastic properties and failure criterion of the projectile significantly influences the accuracy of the results, particularly regarding the final velocity and deformation of the sample. Experimental tests were carried out for impact angles ranging from 0° to 35°, measuring the projectile velocity before and after passing through the sample and analysing the perforation process using a high-speed camera. Based on the results, the critical ricochet angle for 1.3964 steel and 7,62 MSC bullet was between 60° and 70°. The results demonstrate that numerical simulations are an effective and economical tool for designing anti-armor protection. It was also shown that the appropriate selection of material parameters and the projectile model is crucial for achieving agreement between simulation results and experimental data.

Keywords: FEM, shooting, ricochet, rapid change process, dynamic explicit

FANCY FENCE - A NEW TYPE OF ANTI-TERRORIST RETRACTABLE GATE - DESIGN AND REAL CRASH TEST

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Abstract: In recent years, increasing demand has been observed for effective and modern infrastructure protection systems, particularly in response to vehicle-ramming terrorist threats. Fancy Fence has developed a dedicated anti-terrorist gate designed to protect critical facilities against such attacks. The solution meets the stringent requirements of ASTM F2656 and IWA 14-1 standards with respect to vehicle impact resistance. A key feature distinguishing the Fancy Fence gate is its fully retractable design, allowing the structure to be completely concealed below ground level in the open position. This paper presents the engineering development process, including Finite Element Method (FEM) analyses, as well as the manufacturing and certification of a prototype of a novel anti-terrorist gate. The primary design objective was to stop an N2B-class vehicle with a mass of 7.2 t traveling at speeds up to 48 km/h. A critical performance requirement was achieving penetration class P1 (penetration $\leq$ 1 m), ensuring that the vehicle is immobilized and prevented from passing beyond the gate line after impact. The design process required balancing resistance to extreme dynamic loading with structural compatibility within the existing Fancy Fence product portfolio. Additional requirements included operational ergonomics, architectural aesthetics, and integration with surrounding infrastructure. SolidWorks was used for mechanical design and linear static strength verification, while ANSYS LS-DYNA was applied for explicit dynamic simulations of vehicle impact. Experimental validation was performed through a full-scale crash test conducted at the CTS Crash Test Service GmbH facility in Germany. Due to high logistical and organizational costs, the test was performed only once. Performance assessment was based on penetration measurements and evaluation of post-impact structural integrity. After the crash test, the impacting vehicle was classified as non-operational, confirming the effectiveness of the developed anti-terrorist gate.

Keywords: anti-terrorist gate, FEM simulations, vehicle impact, crash test, LS-DYNA, SolidWorks Simulation, infrastructure security, Fancy Fence, underground gates

FEM-BASED ANALYSIS OF SOIL SUFFOSION TRIGGERED BY PIPELINE LEAKAGE

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Abstract: Failures and damage to pipelines, along with associated leakages, occur in water supply systems throughout their entire service life. Such events entail economic costs resulting from water losses and the need to repair the damaged network. Moreover, water leakages may induce suffosion processes, during which the washing out of soil particles can lead to the formation of voids beneath the ground surface and, consequently, ground subsidence. These phenomena pose a threat to the safety of people and property, particularly in urban areas. For suffosion to occur, two fundamental conditions must be satisfied: a geometric condition, related to the soil grain size distribution, and a hydraulic condition, associated with the velocity of water flow through soil pores. The aim of this paper is to analyze the influence of hydraulic pressure in the water supply system, groundwater table position, and soil permeability on the velocity at which water spreads within the soil, with particular emphasis on the possibility of fulfilling the hydraulic condition for suffosion. The study is based on numerical simulations of water supply system failures carried out for various computational scenarios using FEFLOW v. 5.3, based on the finite element method. The simulation results were experimentally verified through a controlled water supply failure conducted under real conditions.

Keywords: water pipes, leakages, FEFLOW, FEM, suffosion

EFFECT OF THE CROSS-SECTION ON THE ENERGY ABSORPTION AND BENDING BEHAVIOR OF BENT TUBES

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Abstract: When a bent tube is subjected to transverse load, it has the capacity to resolve this load into both axial and bending components, allowing the structure to obtain a combined stress state. This confers a higher structural efficiency respect to straight tubes. The crashworthiness performance of bent tubes depends on multiple factors such as material, configurations, and geometrical parameters. However, studies on the cross-section of bent tubes has been scarcely reported despite presenting a better performance than their straight counterparts when subjected to bending loads. In this sense, the current article, firstly evaluated the mechanical response of straight versus bent tube. Lately, a second analysis evaluates numerically the effect of the cross-section on bending resistance and energy absorption of bent tubes. For this purpose, five bent tubes with different cross-sections including circular, triangular, square and rectangle shapes were numerically evaluated by three-point bending test. In all cases, the bent tubes presented the same geometric characteristics and mass. During the simulation, the tubes were conferred with elastoplastic models for aluminum alloy 6063-T5. The feasibility of numerical results was guaranteed since an experimental validation of a circular straight tube under three-point test was presented. According to results, the effectiveness of bent tube respect to straight tube was obtained since and improvement on Ea up to 22.84% was computed. On the other hand, the importance of the cross-section of the crashworthiness performance of bent tube was confirmed. A better crashworthiness performance is obtained when a circular cross-section is used. From this, a CFE value of 0.87 was computed, yielding 13.14% respect to the lowest CFE obtained for the rectangular bent profile.

Keywords: bent tubes; structural strength; energy absorption; thin-walled tubes; finite element analysis

EQUIVALENT STATIC FINITE ELEMENT ANALYSIS OF HUMAN SKULL LOADING UNDER CONDITIONS REPRESENTATIVE OF MOTORCYCLE COLLISIONS

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Abstract: Motorcycle accidents are a major cause of severe head injuries, and numerical modelling provides a useful approach for investigating the mechanical response of cranial structures under collision-related loading. This study presents a comparative equivalent static finite element analysis of a patient-specific human skull reconstructed from computed tomography data. The novelty of the study lies in the use of an anatomically reconstructed CT-derived skull model to systematically compare cranial stress and displacement responses under equivalent static loading conditions corresponding to a consistent series of motorcycle collision velocities from 40 to 140 km/h. The skull was represented as a homogeneous, isotropic, linearly elastic structure, and equivalent resultant forces corresponding to 40, 60, 100, and 140 km/h were distributed over the superior cranial surface. The model was constrained at the occipital condyles. The calculated peak von Mises stress reached approximately 146 MPa at 40 km/h and increased to approximately 902 MPa at 140 km/h. The highest stress concentrations occurred near the occipital constraint region and in the frontal cranial area, whereas the largest displacements occurred in regions distant from the fixation points. Because the model did not include damage initiation or post-failure behaviour, stresses exceeding the literature-based cranial bone fracture threshold were interpreted as comparative indicators of potential structural failure rather than realistic post-fracture stresses. The proposed approach provides a simplified framework for identifying loading conditions and anatomical regions in which cranial bone strength criteria may be exceeded and establishes a basis for future nonlinear and transient analyses.

Keywords: finite element analysis; human skull; equivalent static loading; motorcycle collision; cranial biomechanics; fracture initiation; computed tomography

DESIGNING VEHICLE STRUCTURES USING MATERIALS WITH A LOW CARBON FOOTPRINT

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Abstract: The development of vehicle designs is currently focused on energy optimisation with a view to reducing their negative impact on the environment. One area of development involves the use of renewable or naturally based materials. This article presents simulation analyses of the monocoque structure of a prototype vehicle designed for the Shell EcoMarathon competition. The new vehicle structure was analysed, considering both conventional materials (carbon fibre) and natural materials (linen). The research was conducted on the new monocoque structure of the vehicle, utilising material tests carried out by the authors. The results of FEM analyses of the structure loaded with the driver's weight are presented. Analyses were presented showing that the use of linen reduces the structural strength compared to a carbon fibre structure. With the same material thickness, the deformation and load on the structure increase significantly when natural materials are used. It was also demonstrated that, in order to maintain deformation at the same level, it is necessary to increase the thickness of the structure by 30%, which results in a 10% increase in the vehicle's mass. However, it was shown that the use of natural materials will allow for the achievement of a correct structure.

Keywords: vehicle, composites, FEM, simulations

DEVELOPMENT OF A DIGITAL CAD MODEL OF THE LUBLIN R-XIIID AIRCRAFT

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Abstract: The reconstruction of historical aircraft often requires combining limited archival data with modern engineering tools. This challenge is particularly evident in the case of the Polish pre-war reconnaissance and liaison aircraft Lublin R-XIIID, for which no complete technical documentation has survived. The objective of the presented work is the development of a comprehensive digital CAD model of the Lublin R-XIIID aircraft as a basis for the construction of a full-scale flying replica. The modelling process was carried out in the CATIA V5 environment using contemporary computer-aided design techniques. Available archival drawings, photographs, and surviving technical information were collected and analysed. Historical drawings were imported into the CAD system and scaled to the known overall dimensions of the aircraft using the Sketch Tracer module, enabling the reconstruction of the external geometry and creation of a conceptual model. Based on the reconstructed outer shape, detailed structural models of the fuselage, wing, empennage, and landing gear were developed. One of the principal challenges was the recreation of the original design philosophy of a 1930s aircraft while simultaneously adapting the structure to modern engineering practices and manufacturing requirements. Particular attention was devoted to the wing structure. The original wooden spars and ribs were replaced by metallic counterparts while preserving the number, arrangement, and aerodynamic geometry of the original components. The redesigned wing incorporates metallic spars consisting of a web reinforced by pairs of angle sections, while the ribs were designed as thin-walled sheet-metal structures. Composite materials were used only in selected non-structural fairings, such as wingtip fairings and aerodynamic covers. The resulting CAD model represents the primary structural configuration of the Lublin R-XIIID aircraft and provides a foundation for further development activities, including control system integration, technical documentation preparation and finite element structural analyses. The presented methodology demonstrates how modern CAD tools can support the reconstruction and preservation of historical aerospace heritage while meeting contemporary engineering standards.

Keywords: istorical aircraft reconstruction, CAD modelling, CATIA V5, Lublin R-XIIID, aerospace heritage, digital engineering

MATERIAL PROPERTIES AND STRUCTURE RESEARCH METHODS

THE ROLE OF CARBON ADDITIVES IN SHAPING THE MECHANICAL PROPERTIES OF ABS AND ASA POLYMER FILAMENTS IN THE FDM PROCESS

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Abstract: This study examines the influence of carbon additives on selected mechanical properties of ABS and ASA filaments used in fused deposition modeling (FDM). Test specimens with varying infill densities (10–30%) and print orientations were fabricated and analyzed using tensile, flexural, and dynamic mechanical analysis (DMA) to assess both static and viscoelastic behavior. The results show that the effect of carbon reinforcement strongly depends on the polymer matrix. For ABS, the addition of carbon generally did not improve mechanical performance and often led to deterioration, likely due to reduced interlayer adhesion, increased delamination, and non-optimized processing parameters. In contrast, ASA-based composites demonstrated clear improvements in strength and stiffness. ASA with carbon additive (ASA CF) exhibited the highest and most stable elastic modulus values, along with favorable viscoelastic properties over a wide temperature range. DMA results supported findings from tensile and bending tests. ASA CF showed superior stability of the storage modulus (E′), while ABS CF displayed greater variability and a less distinct glass transition region. The impact of infill density on mechanical properties was relatively minor compared to material type and carbon addition. Print orientation also had limited influence, except for ASA CF, where the Y orientation improved performance. Overall, the study indicates that carbon modification in FDM filaments requires careful material selection and process optimization. While carbon additives enhance ASA performance, they do not provide expected benefits for ABS under unchanged processing conditions.

Keywords: ABS, ASA, FDM, tensile test, dynamic mechanical analysis, viscoelastic, carbon additive

PRELIMINARY RESEARCH OF DENSITY INFILL INFLUENCE ON THE TENSILE STRENGTH OF THERMOPLASTIC POLYURETHANE (TPU) 3D PRINTED ELEMENTS IN FUSED DEPOSITION MODELING (FDM) METHOD

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Abstract: Thermoplastic polyurethane (TPU) is one of elastomers featuring high elasticity and resistance to mechanical loading. It combines elastomeric properties with the capability to be processed using methods typically used for thermoplastic materials. This makes TPU an attractive alternative to conventional injection moulding materials. TPU has a wide range of applications, including automotive, medical, and footwear industries, as well as automation systems. The objective of this study was to determine the ultimate tensile stress value and strain behaviour of TPU under uniaxial tensile loading. The specimens of 20%, 30%, 50% and 90% infill density were prepared as per ISO 37:2017, using the Fused Deposition Modelling (FDM) technique. The specimens did not have upper and lower solid layers. The following mechanical properties were determined based on the output of tensile tests conducted with an optical extensometer, using the chosen methods and the obtained stress-strain curves: tensile strength, elongation at break, elasticity modulus, and yield strength. The results presented in this paper allowed determination of ultimate tensile stress vs. infill density relationship.

Keywords: thermoplastic polyurethane, fused deposition modeling, strain test, mechanical properties, elastomers

DEGRADATION BEHAVIOR OF RESIN-BASED COMPOSITES UNDER SIMULATED ORAL CONDITIONS: A COMPARATIVE STUDY OF MICROHARDNESS, SURFACE ROUGHNESS, AND WATER-RELATED PROPERTIES

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Abstract: Resin-based composites are widely used in direct restorative dentistry; however, their long-term performance depends on the interaction between material composition, surface condition, and exposure to chemically diverse oral environments. Experimental characterization of these degradation processes is important for clinical material selection, but also for the development, calibration, and validation of numerical models describing the mechanical and physicochemical stability of restorative materials. This study evaluated six commercially available RBCs representing different material classes: conventional, bulk-fill, flowable, and bioactive composites. Disc-shaped specimens were assigned to polished or unpolished groups and aged in distilled water, artificial saliva, acidic solution (pH ≈ 4), or oxidative solution (3% hydrogen peroxide) for 24 hours, 7 days, and 30 days. Microhardness, surface roughness, SEM morphology, water sorption, solubility, and contact angle were assessed. Statistical analysis was performed using three-way ANOVA with Tukey's post hoc test ($\alpha = 0.05$). All materials showed time- and medium-dependent degradation, expressed as a progressive decrease in microhardness and an increase in surface roughness. After 30 days, hardness loss ranged from 4–6% in distilled water to over 30% in oxidative medium. The highest susceptibility to degradation was observed in ACTIVA BioACTIVE and SDR Flow+. Surface roughness exceeded the clinical threshold of Ra = 0.2 µm under acidic and oxidative conditions, while water sorption ranged from 18 to 43 µg/mm³ and was greater in bioactive and flowable materials. The obtained dataset provides experimentally determined degradation parameters that may be used as material input data, boundary-condition references, or validation benchmarks for computational analyses of dental composite behavior. In particular, hardness loss, roughness evolution, sorption-related changes, wettability, and surface morphology may support numerical modelling of environmentally induced material degradation. These results may further help parameterize finite element models and verify simulations predicting stiffness loss, surface deterioration, and failure risk.

Keywords: resin-based composites (RBCs), dental composites aging, microhardness, surface roughness, water sorption, wettability, oxidative degradation

INFLUENCE OF SKIN MATERIAL AND SURFACE TREATMENT ON AERODYNAMIC PERFORMANCE

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Abstract: This paper presents an analysis of the influence of material properties and surface treatment of wing skin on aerodynamic characteristics, based on experimental investigations conducted in a wind tunnel. The subject of the study was a 1:10 scale wing model with a geometry closely resembling the NACA 64A203 airfoil, which is applied, among others, in the design of the F-35 aircraft. The experiments were carried out in the wind tunnel of the Polish Air Force University. To evaluate the effect of skin type, two wing models with different structural configurations were manufactured. The first model consisted of a wooden frame covered with modeling film, while the second was a self-supporting structure made of carbon fiber composite. The study focused on identifying differences in aerodynamic characteristics resulting from the applied materials and surface finishing quality. The obtained results allowed for the assessment of the influence of structural stiffness and surface roughness on key aerodynamic parameters, such as lift and drag. The experimental findings revealed significant differences between the analyzed configurations, highlighting the importance of proper material selection and surface treatment in the design of both model-scale and full-scale wing structures.

Keywords: aerodynamic performance, wing skin, surface roughness, composite materials

RESULTS OF LABORATORY TESTS OF THE STATIC AND DYNAMIC FRICTION COEFFICIENTS OF FERTILIZER GRANULES AGAINST THE STRUCTURAL MATERIALS OF SEED DRILLS USING A ROTARY TEST STAND

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Abstract: The paper presents the results of laboratory investigations of static and dynamic friction coefficients of mineral fertilizer granules (urea) against structural materials used in agricultural seed drills. The experiments were carried out using an original rotary test stand enabling the analysis of tribological phenomena under conditions similar to the actual operating conditions of fertilizer metering systems. The scope of the study included the analysis of interactions between fertilizer granules and contact surfaces made of structural steel and polymer materials. The influence of motion parameters and the type of contact material on the values of static and dynamic friction coefficients was evaluated. The obtained results, subsequently implemented in simulation studies, indicate a significant influence of the working surface properties on the transport process of granular material and the stability of material flow. The developed research stand may constitute a useful tool supporting the design of fertilizer metering systems and the selection of materials limiting motion resistance and adhesion phenomena in the working elements of agricultural seed drills.

Keywords: friction coefficient, fertilizer granules, rotary test stand, agricultural engineering, simulation studies

THE INFLUENCE OF THE MOLD SIZE ON PROPERTIES OF GFRP MADE BY INFUSION METHOD

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Abstract: The aim of the work is to investigate the influence of the mold size on the properties of a layered composite produced by the infusion method, i.e. how the form affects the propagation of the resin composition and the strength characteristics of the laminate. The scope of the work includes the following activities: production of one composite by the infusion method (which was divided into twelve research sectors), examination of individual samples from each sector under a microscope (in terms of the content of air voids in the material structure), examination of the internal and external structure of the laminates under a microscope, tests of the mechanical properties of samples prepared from the produced composite (bending strength test, impact strength test and tensile strength test). For the purpose of this work the nine layers composite was made with reinforcement of glass fiber roving fabric with a weight of 390 g/m^2 and a saturation of 370 g/m^2 and a "twill" weave. MGS L285 epoxy resin and H287 hardener were used for production. The resin and hardener were mixed in a 100:40 ratio (according to the manufacturer's recommendations). In order to facilitate the removal of the composite from the mold, a delamination fabric was used. In addition, a special mesh was used to facilitate the propagation of the resin mixture and its even flow through the mold. The final dimensions of the composite were 100 x 100 cm. The composite was divided into 12 zones and tested. The highest bending strength was demonstrated by samples from sector five. In the tensile test, the best result was achieved by zone seven. The ambiguous results show the high influence of the mold (especially its size) on the propagation of the resin mixture in the infusion process.

Keywords: layered composites, composite manufacturing processes, infusion method, GFRP (glass fiber reinforced polymer)

NON-DESTRUCTIVE ANCHOR CONDITION CLASSIFICATION IN UNDERGROUND MINING USING FFT ANALYSIS AND TRANSFER LEARNING

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Abstract: In underground mining, ensuring the integrity of roof support systems is critical for operational safety. Traditional methods of assessing the condition of mining anchors, such as pull-out tests, are destructive, costly, and provide limited spatial coverage. This paper introduces a non-destructive approach based on feature-level transfer learning, where anchor condition data collected in the geomechanically stable Wieliczka Salt Mine are used to support classification in the more dynamically challenging environment of the KWK Piast-Ziemowit Ruch Ziemowit coal mine. The proposed system integrates a self-excited vibration measurement setup with a Random Forest classification algorithm. Anchors subjected to different installation and boundary conditions generate distinct frequency-domain responses, which are captured through high-resolution signal acquisition and analyzed using Fast Fourier Transform (FFT). During the initial phase, reference data were collected in Wieliczka, where anchors were known to be correctly or incorrectly installed. These labeled datasets enabled the construction of a structured feature space based on selected spectral and harmonic descriptors related to anchor tension, installation quality, and vibration stability. Transfer learning was then employed to adapt diagnostic information extracted from the salt mine data to the more corrosive and mechanically heterogeneous setting of the Ziemowit coal mine. This was done using feature-level adaptation and limited target-domain calibration rather than retraining the model from scratch. Additional testing was used to evaluate whether the classifier could distinguish between properly and improperly installed anchors under varying environmental and installation conditions. The approach shows potential for transferable, in-situ anchor assessment without the need for destructive testing or extensive recalibration. This technique addresses an important challenge in mining engineering by evaluating whether non-destructive vibration-based diagnostics can be transferred between mining environments with different geological, structural, and mechanical conditions.

Keywords: transfer learning, non-destructive testing, string anchors, underground mining, vibration diagnostics, frequency-domain analysis, machine learning, structural health monitoring

EVALUATION OF MOISTURE CONTENT IN 600 AERATED CONCRETE USING TDR SENSORS WITH POLYLACTIDE HOUSING

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Abstract: This paper analyzes the environmental parameters of aerated concrete 600 using a TDR (Time Domain Reflectometry) meter. The application of 3D printing in non-invasive measurements of environmental parameters of building envelopes is presented. The operating principle of the prepared meters is demonstrated. Probes with polylactide housings were developed for the meter. Previous measurements using PLA (polylactide) in scientific research on moisture content and permittivity of this material are presented. Non-invasive measurements of aerated concrete 600 samples were performed to determine the moisture content in the tested samples. The construction of the non-invasive TDR sensor is presented and the properties of the materials used in the tests are discussed. The permittivity and permittivity of the material were calculated and the root mean square error (RMSE) was determined using classical computational methods and machine learning techniques, focusing on GPR and SVM models. Final conclusions are presented along with an analysis of the obtained test results.

Keywords: TDR, moisture content,600 aerated concrete, 3D printing, PLA

MECHANICAL PROPERTIES OF FLAX FIBRE-REINFORCED BIO-COMPOSITES

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Abstract: One of the main directions of development in automotive engineering is reducing the environmental impact of vehicle production and operation. Consequently, structural solutions with the lowest possible carbon footprint, particularly those based on renewable resources, are highly sought after. This paper presents the results of mechanical property tests (flexural and tensile strength) on composite laminates made of a bio-epoxy matrix reinforced with flax fiber fabric (linen). The laminates were intended as a material for the monocoque of a prototype ultra-efficient vehicle developed for the Shell EcoMarathon competition. The aim of the study was to determine the tensile and flexural strength limits and the modulus of elasticity for various configurations of a flax-fibre-based composite, and to determine the statistical variation in these values. The experiments were conducted to compare laminates based on three fabric types differing in areal weight (152, 230, and 300 g/m²) and two reinforcement architectures (0º/90º and ±45º). The data gathered during standardized tensile and three-point bending tests were analyzed using Student's t-test. The results demonstrate that Young's modulus is statistically independent of fabric weight but strongly depends on fiber orientation, and ranges from 3.61 GPa for the ±45º angle-ply layout to 5.68 GPa for the 0º/90º cross-ply arrangement. The fiber orientation significantly affects the ultimate tensile and flexural strengths, yielding up to 32% higher values for the orthotropic 0º/90º configuration. Statistical analysis highlights notable data dispersion (with the tensile strength coefficient of variation reaching 24.2%) attributable to the structural non-uniformity of natural fibers. Despite this variance, the analyzed bio-composites exhibit high specific stiffness and can be considered a candidate material for lightweight, low-carbon automotive components.

Keywords: biocomposites, flax fiber, mechanical testing, statistical analysis, sustainable automotive

NUMERICAL ANALYSIS OF HEAT TRANSPORT IN DISPERSIVE COMPOSITES WITH MICROENCAPSULATED PCMS: INFLUENCE OF VOLUME FRACTION, ELEMENTARY CELL SIZE AND MODEL DIMENSIONALITY

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Abstract: Dispersive composites are widely used in materials engineering and industrial applications, therefore, the reliable determination of their effective thermal properties is essential for the analysis, modelling and design of this group of materials. The thermal response of such composites is governed not only by the inherent properties of their components, but also by their microstructure, the volume fraction of the dispersed phase and the geometrical representation adopted in numerical models. Composites containing phase change materials (PCM) are of particular interest, as their ability to store and release latent heat may significantly affect heat transport at both local and global scales, especially under transient thermal conditions. Although many analytical homogenization models for estimating the effective thermal conductivity of dispersed composites exist, phase change effects are still not fully represented in most classical analytical formulations. Therefore, the incorporation of a PCM into the dispersed phase introduces an additional modelling challenge. This study presents a numerical investigation of heat transport in a polymer type matrix composite containing uniformly distributed spherical polymer inclusions filled with a phase change material. Two-dimensional and three-dimensional models were developed and compared, considering different volumes fractions of inclusions and different sizes of the representative elementary cell. The simulations were performed under both steady-state and transient conditions in order to assess the effects of model dimensionality and elementary cell size on effective thermal properties. The obtained results make it possible to identify a compromise between computational accuracy and numerical cost, as well as to indicate the range in which two-dimensional models may serve as an effective simplification of three-dimensional models. The presented analysis provides a basis for selecting the size of the representative elementary cell in simulations of heat transport in dispersive composites containing phase change material-filled inclusions.

Keywords: dispersive composites, phase change material, effective thermal properties, numerical modelling, representative volume element

MICROHARDNESS–TOUGHNESS TRADE-OFF AND ANISOTROPY REDUCTION IN DMLS Ti_6Al_4V INDUCED BY POST-PROCESSING HEAT TREATMENT

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Abstract: Direct Metal Laser Sintering (DMLS) of Ti6Al4V enables the fabrication of complex structural and biomedical components, but the resulting microstructure, residual stresses and build-orientation effects strongly influence damage initiation and fracture resistance. Experimentally determined material characteristics are therefore essential not only for mechanical assessment, but also as reference data for numerical modelling aimed at reducing repeated fabrication and destructive testing. This study investigated the influence of post-processing heat treatment on the microhardness, Charpy impact toughness, anisotropy and fracture mechanisms of DMLS Ti6Al4V. Specimens were fabricated in two build orientations, XY and XZ, using optimized parameters corresponding to a volumetric energy density of 127 J/mm³, and were annealed at 650, 750, 850 and 950 °C for 2 h under argon. Vickers microhardness testing, instrumented Charpy impact testing and SEM fractography were used to evaluate mechanical response and fracture behaviour. Heat treatment caused a progressive decrease in hardness from 401.7 to 326.0 HV5, while mean impact toughness increased from 14.29 to 52.41 J/cm². The hardness anisotropy coefficient decreased from 1.078 to 1.015, and the impact-toughness anisotropy coefficient from 1.397 to approximately 1.03 after high-temperature annealing. SEM observations revealed a transition from quasi-brittle fracture with cleavage-like facets and defect-assisted crack initiation to predominantly ductile fracture governed by microvoid coalescence. These changes are consistent with α′ martensite decomposition, residual stress relaxation and microstructural homogenisation. The obtained dataset may be used as input, calibration and validation material for finite element analyses, damage models and computer-aided assessment of heat-treated DMLS Ti6Al4V. Such experimentally grounded numerical models may support prediction of hardness–toughness relationships, anisotropic response and fracture risk without manufacturing and destructively testing numerous additional specimens. Therefore, the results constitute a practical basis for predictive numerical workflows aimed at optimizing heat-treatment conditions and limiting further trial-and-error testing.

Keywords: Ti6Al4V, DMLS, heat treatment, microhardness, Charpy impact toughness, anisotropy

INFLUENCE OF DEPOSITION RATE ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF TIN LAYERS: EXPERIMENT AND SIMULATION

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Abstract: The development of high-performance functional surfaces relies heavily on magnetron sputtering, a precise physical vapor deposition technique that enables atomic-scale layer deposition. This study focuses on the structure and morphology evolution of samples deposited on substrates with different rates and samples of different total thickness deposited at the same rate. We used TiN targets and DC sputtering. Deposition rates for the TiN layers were varied from 0.5 Å/s to 1.5 Å/s , while the total thickness varied from 20 nm to 100 nm. As a substrate, we use tool steel. The resulting layers were characterized by X-ray diffraction (XRD) and atomic force microscopy (AFM) to assess their crystalline structure, phase composition, and surface topography. Additionally, we determined some mechanical properties using the nanoindentation method. The aim of the study is to connect the microstructure, morphology, and friction factor of TiN thin films with technological parameters. To support the interpretation of X-ray analysis, a computer program based on numerical simulations was used to calculate X-ray profiles from thin films. Software generates a model of thin layers with crystalline structure and calculates XRD patterns for comparison with experimental results. As initial simulation parameters, we used those obtained from phase and structure analysis. These tools, with rigorous empirical validation, could be used in the initial stages of predicting the future structure of thin films for DC sputtering deposition technology. The hardness and elastic modulus were determined from nanoindentation load-displacement curves.

Keywords: magnetron sputtering, PVD, thin layers, TiN, Titanium, Nitrogen, X-ray difraction, tribology

APPLICATION OF IMAGE ANALYSIS FOR THE ASSESSMENT OF CAVITATION EROSION PHENOMENA FOR THE THERMAL SPRAYED COATINGS

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Abstract: Cavitation erosion is a major degradation mechanism affecting structural materials operating in liquid environments, particularly components of fluid-flow machinery such as pumps, hydraulic turbines, valves, and marine propellers. The collapse of vapour-gas bubbles generates localized shock waves and high-velocity microjets, causing surface damage in the form of pits, craters, and microcracks. These processes lead to material loss, reduced service life, and increased maintenance costs, making the assessment of cavitation resistance an important issue in materials engineering. This study investigates the applicability of digital image processing and analysis for the quantitative assessment of cavitation-induced surface degradation. The proposed methodology enables the determination of damaged surface areas, comparison of the cavitation resistance of protective coatings, and monitoring of damage evolution with increasing cavitation exposure time. The theoretical part outlines the fundamentals of cavitation erosion, degradation mechanisms, and their effects on engineering materials, highlighting the role of digital image analysis as a complementary tool to conventional evaluation methods. The experimental investigation included cavitation testing, microscopic image acquisition, and the development of an original image-processing algorithm for automated detection and quantification of damaged areas. Cermet coatings were evaluated after identical exposure times, whereas ceramic coatings were examined after different cavitation durations. The results demonstrate that digital image analysis is a repeatable, objective, and effective method for assessing cavitation erosion. The proposed approach enables comparative evaluation of coating performance and monitoring of surface degradation, providing valuable support for durability assessment and lifetime prediction of protective coatings under service conditions.

Keywords: experiment, energy harvesting, modelling

EFFECTIVENESS OF SELECTED NDT METHODS FOR INSPECTION OF A 12-PLY AEROSPACE CFRP LAMINATE

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Abstract: The increasing use of carbon fiber reinforced polymers (CFRP) in the primary structures of modern aircraft necessitates advanced diagnostic techniques for Barely Visible Impact Damage (BVID). Such damage, typically caused by low-velocity impacts like tool drops, poses a significant threat to flight safety because it remains undetectable during routine visual inspections while causing hidden degradation of the laminate's mechanical properties. This study utilized aviation-certified materials: a Twill weave carbon fabric (285 g/m²) and a specialized aerospace-grade epoxy resin system. Specimens were fabricated with 12 plies in a symmetric stacking sequence, where layers were rotated relative to one another to ensure balanced multidirectional reinforcement. Samples (80x60 mm) were produced via hydraulic pressing (30 tons), waterjet cutting, and thermal curing at 80°C for 10 hours. Controlled impact damage was induced using an Instron CEAST 9340 drop-weight tester at energies ranging from 1.0 J to 3.0 J. Technical evaluation utilized an Olympus BX53M microscope, a Woodpecker WP-632 digital tap tester, and a Dolphicam 2 ultrasonic system. Microscopy proved insufficient, identifying only surface-level cracks. While the tap test enabled rapid localization of defective areas, ultrasonic testing provided the highest precision for subsurface delamination visualization and accurate area measurement. A critical finding is that manufacturing inconsistencies significantly impact damage resistance, providing essential experimental data for computational modeling. Local thickness variations directly determined damage extent; a thickness deviation as small as 0.26 mm led to an almost twofold increase in the delamination area under the same impact energy. These results provide vital benchmarks for validating numerical models, demonstrating that predictive tools must account for manufacturing tolerances rather than assuming uniform laminate thickness. Integrating high-precision NDT mapping with numerical modeling is essential for accurately predicting the structural integrity of aerospace composites.

Keywords: carbon composites, NDT, BVID, ultrasonography, delamination

PORTABLE MULTICHANNEL ULTRASONIC TOMOGRAPHY FOR THREE-DIMENSIONAL IMAGING OF CONCRETE DEFECTS

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Abstract: This paper presents a portable multichannel ultrasonic tomography system for non-destructive three-dimensional imaging of internal heterogeneities in concrete structures. The instrument combines a modular matrix probe based on dry-contact DPC transducers with 32 independent transmit-receive channels, parallel acquisition, FPGA control, 12-bit conversion, and an embedded CM5 computing platform. The probe architecture supports beam steering and focusing without a coupling agent, which facilitates field inspection of rough surfaces. The reconstruction workflow removes baseline drift, derives an analytic representation of the transmitted pulse, applies regularized frequency-domain matched filtering, and detects arrival peaks after suppression of the direct sensor-to-sensor path. Detected time-of-flight values are associated with voxels using a precomputed propagation-distance model, while a voting scheme integrates evidence from multiple transmitter-receiver pairs. This aggregation reduces sensitivity to individual waveform amplitudes and highlights locations repeatedly confirmed by independent propagation paths. Measurements performed on a concrete block containing steel reinforcement and a PEX pipe demonstrate the feasibility of volumetric localization of embedded discontinuities. The developed platform integrates excitation, acquisition, processing, visualization, battery operation, and a touchscreen interface in a compact architecture, providing a practical basis for rapid on-site diagnostics of concrete structures.

Keywords: ultrasonic tomography, non-destructive testing, concrete diagnostics, direct point contact transducers, time-of-flight, matched filtering, beamforming, voxel reconstruction

EFFECT OF MATERIAL COMPOSITION AND EMBOSSING PROCESS PARAMETERS ON THE PUNCTURE RESISTANCE OF THREE-LAYER POLYETHYLENE FILMS WITH RECYCLED CONTENT

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Abstract: The increasing use of recycled polyethylene in multilayer films requires maintaining adequate mechanical performance under industrial processing conditions. This study investigates the puncture resistance of three-layer polyethylene films containing different proportions and types of recycled material and subjected to mechanical embossing. Three material groups were analysed: films containing approximately 54% recycled LDPE, approximately 54% recycled material with HDPE as the predominant component, and approximately 65% recycled material with a substantial HDPE fraction. The experimental programme included different embossing patterns, embossing intensity settings represented by the embossing roller axis distance parameter, and industrial film line speeds. Puncture resistance was evaluated using the mass required to damage the film. The analysis focused on determining the effects of material composition, embossing pattern, embossing intensity, and line speed, as well as their interactions. The results indicate that puncture behaviour cannot be explained solely by the total recycled content. Material composition and embossing conditions are important factors determining puncture performance, while the influence of line speed is substantially smaller. The study identifies material–process configurations providing increased puncture resistance and demonstrates the need for joint optimisation of recycled material composition and embossing conditions.

Keywords: multilayer polyethylene films, recycled polyethylene, mechanical embossing; puncture resistance; process parameters

DIRECTIONAL ANISOTROPY OF TEAR RESISTANCE IN EMBOSSED THREE-LAYER POLYETHYLENE FILMS CONTAINING RECYCLED MATERIAL

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Abstract: Mechanical anisotropy is an important characteristic of blown polyethylene films because their properties in the machine direction and cross direction may respond differently to material composition and subsequent processing. This study investigates the tear resistance of embossed three-layer polyethylene films containing high proportions of recycled material, with particular emphasis on differences between the machine direction (MD) and cross direction (CD). Three groups of films differing in recycled polyethylene content and type were analysed. The experimental variables included embossing pattern, embossing intensity represented by the embossing roller axis distance setting, and film line speed. Tear resistance was evaluated separately in MD and CD, and the effects of material and processing factors and their interactions were assessed using non-parametric multifactorial methods. The analysis demonstrates pronounced differences in tear behaviour among the material groups and confirms that the response to embossing is direction-dependent. The effects of embossing pattern and embossing intensity differ between MD and CD, whereas changes in industrial line speed have a comparatively limited influence. The results show that tear performance should not be represented by a single averaged mechanical characteristic. Separate consideration of MD and CD provides a more reliable basis for selecting recycled material compositions and embossing parameters for industrial multilayer film production.

Keywords: multilayer polyethylene films, recycled polyethylene, mechanical embossing, tear resistance, directional anisotropy

IDENTIFICATION OF A ROBUST EMBOSSING PROCESS WINDOW FOR THREE-LAYER RECYCLED POLYETHYLENE FILMS BASED ON MULTIPLE MECHANICAL PERFORMANCE CRITERIA

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Abstract: Industrial optimisation of embossed multilayer polyethylene films cannot be based on a single mechanical property because processing conditions that improve one failure mode may adversely affect another. This study proposes a multi-response approach for identifying a robust embossing process window for three-layer polyethylene films containing high proportions of recycled material. Experimental data from three complementary laboratory studies were integrated, covering tensile strength in the machine and cross directions, puncture resistance, and tear resistance in both directions. The analysed factors included recycled material composition, embossing pattern, embossing intensity represented by the embossing roller axis distance setting, and industrial film line speed. Mechanical responses were normalised relative to corresponding reference films or technological requirements to enable comparison of properties expressed in different units. The objective was not to maximise an individual response but to identify material–process configurations that provide simultaneously stable tensile, puncture, and tear performance. The integrated analysis indicates that material composition and embossing intensity are the key variables requiring joint consideration, whereas production speed within the investigated industrial range is less critical. The proposed approach enables identification of processing regions in which high recycled content can be combined with balanced mechanical performance without relying on optimisation of a single strength characteristic.

Keywords: multilayer polyethylene films, recycled polyethylene, mechanical embossing, multi-response optimization, process window

IMPLEMENTATION OF ADDITIVE MANUFACTURING TECHNOLOGY IN THREADED FASTENERS

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Abstract: The research paper aimed to evaluate the feasibility of utilizing 3D printing technology via the FDM (Fused Deposition Modeling) method in the manufacturing process of threaded components. The scope of the study included analyzing the impact of printing orientation on the dimensional accuracy of external metric threads produced in accordance with the International Organization for Standardization ISO 4014 standard, within the 6g accuracy class. Three materials with distinct mechanical properties and applications were used in the study: Hyper PLA, UV ABS, and PETG-CF. These materials were selected due to their varying performance characteristics, such as strength, thermal resistance, and the presence of reinforcing additives. The samples were fabricated in three different orientations relative to the printer's build plate: the Z orientation, where the thread axis was perpendicular to the working surface; the XY orientation, where the thread axis was parallel to the bed; and the 45° orientation, where the thread axis was positioned at a 45-degree angle to the build plate. The analysis focused on the effect of model positioning on the reproduction accuracy of key geometric parameters of the thread, including pitch, thread profile angle, minor diameter, pitch diameter, and major diameter. Measurements were conducted using two measuring devices. Preliminary geometric analysis was performed using a measuring microscope, while full testing was carried out using a Mitutoyo PJ-Plus profile projector, enabling a precise evaluation of the fabricated threads' geometry. The obtained results allowed for determining the influence of both the material type and printing orientation on the quality and manufacturing accuracy of FDM-printed threads.

Keywords: 3D printing, fused deposition modeling (FDM), threaded fasteners

LASER SURFACE TREATMENT OF AlSi11CuMiMg PISTON ALLOY

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Abstract: In order to increase the power output and operational reliability, as well as to maximize the thermal efficiency of the piston-ring-cylinder (PRC) system, pistons used in modern internal combustion engines are continuously improved. These improvements mainly concern increasing the surface resistance of areas exposed to high thermo-mechanical loads. One of the latest methods used for this purpose is laser surface melting (LSM). This process enables, among other things, the formation of fine-grained surface structures with a thickness of up to approximately 600 μm, characterized by high microhardness and strength. The aim of the study was to determine the effect of selected laser parameters, i.e. laser beam power P; energy density Ed; and laser melting time tL on the microstructure of a typical piston alloy. The microstructural changes were assessed on the basis of the laser beam radius rb and the surface melt depth zp. The AlSi11CuNiMg alloy was selected for the investigation, and the samples were taken from the piston crown. Using laser powers of 80, 500, 1000, and 1500 W and two beam travel speeds of 0.5 and 1.0 $m \cdot min^{-1}$, it was found that the most favorable laser power range for obtaining the desired surface microstructural changes is 500 to 1000 W. This range ensures effective refinement of the α(Al) solid-solution dendrites. The microhardness of the melted layer reaches approximately 300 HV0.1 and is 4.0 times higher than the HV0.1 value for α(Al) and approximately 2.4 times higher than the HV0.1 value for the unmelted α(Al)+β(Si) structure. The use of higher laser power for Al-Si-Cu-Ni-Mg alloys leads to a loss of material integrity, as well as increased porosity and surface roughness. It was found that the remelted zone contains no eutectic silicon crystals or α(Al)+β(Si) eutectic precipitates, while the α(Al) solid-solution dendrites are refined and retain a texture oriented perpendicular to the direction of laser beam action.

Keywords: Al-Si piston alloys, laser surface melting, microstructure, microhardness

STAINLESS STEEL WELD OVERLAYS PROPERTIES AND ABRASIVE WEAR RESISTANCE

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Abstract: The improvement of the surface durability of structural steels is an important issue in applications involving abrasive wear conditions. This study investigates the properties and abrasive wear resistance of stainless steel weld overlays deposited on S235JR steel substrates using the Tungsten Inert Gas (TIG) welding process. The overlays were produced with ER308LSi filler metal and subsequently characterized by a combination of microstructural, hardness, and tribological investigations. The microstructure and chemical composition of characteristic regions were analyzed using scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS). Hardness distribution across the weld overlay, dilution and substrate was determined by Vickers hardness measurements. To support the quantitative assessment of the metallurgical bonding, a dedicated machine vision script developed in Python was used to evaluate the fusion line geometry and selected geometric characteristics of the deposited layers. Abrasive wear resistance was evaluated using the rubber-wheel abrasion test and benchmarked against AISI 304 stainless steel. Furthermore, SEM observations of the worn surfaces enabled identification of the dominant wear mechanisms and their relation to the microstructural features of the overlays. The results demonstrate that TIG-deposited ER308LSi weld overlays provide effective protection of low-carbon steel substrates against abrasive wear and exhibit favorable mechanical properties, making them a promising solution for regeneration and surface engineering applications.

Keywords: weld overlay, TIG, microstructure, abrasive wear, SEM

EXPERIMENTAL INVESTIGATION OF USING A LINEAR ARRAY OF PIEZOELECTRIC SENSORS TO DETERMINE THE LOCATION OF A MECHANICAL IMPACT ON THE SURFACE OF A LAMINATE

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Abstract: The paper concerns the application of piezoelectric film sensors for detecting and locating impact events on plates made of glass-fiber-reinforced polymer (GFRP) laminates. The aim of the study was to develop and verify a test setup of linear array of piezoelectric sensors and measurement methodology enabling the analysis of signals generated as a result of impact. The study focused on rectangular plates made of glass-fiber-reinforced polymer (GFRP) laminate, measuring 301 × 200 mm with a thickness of approximately 3 mm. The laminate matrix consisted of an MGS L285 epoxy system with an H287 hardener, mixed in a 100:40 weight ratio. The reinforcement comprised nine layers of glass fabric with an areal density of 280 g/m² and a twill weave. All layers were laid out in the same orientation, with no relative rotation between them. The stack of layers was formed using the vacuum bag technique, maintaining a vacuum pressure in the range of 0.8–0.95 bar. The LDT0-028K – an inexpensive component that is widely available on the market – was used as the piezoelectric sensor. PVDF film has a significantly lower elastic modulus, minimal thickness, and low mass than piezo ceramics, allowing it to conform to curved surfaces. Its acoustic impedance is closer to that of many polymers than to that of ceramics, which can facilitate mechanical coupling. Furthermore, PVDF is characterized by a relatively high piezoelectric voltage coefficient a measure of a material's ability to generate an electric field under mechanical stress and is capable of detecting signals across a wide frequency range. Impacts were generated using a steel ball dropped from a specified height, while the signals were recorded using a Keysight DAQ970A data acquisition unit with a DAQM909A module. Simultaneous sampling of four channels enabled comparison of signal waveforms and the occurrence times of the same characteristic waveform feature. The recorded data were analyzed in MATLAB. Based on differences between signals recorded by linear array of sensors it is possible to estimate the location of the event. This makes it possible to narrow down the area where the laminate damage is located, prior to using time-consuming non-destructive testing methods.

Keywords: composite laminates, GFRP, delamination, piezoelectric sensor, PVDF film, impact localization

EXTRUSION OF ALUMINIUM ALLOY COMPONENTS AND SURFACE LAYER MODIFICATION

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Abstract: This study investigated the influence of recycled aluminium and extrusion conditions on the microstructure and mechanical properties of EN AW-6063 aluminium profiles. Profiles produced from primary and recycled aluminium ingots using dies of different geometries were compared. The experimental programme included SEM-EDS chemical composition analysis, metallographic examination, Vickers microhardness measurements and tensile testing. In addition, the surface finish quality of as-extruded, anodized and painted profiles was evaluated, while the anodized surface was further assessed using a colour spot test. The microstructure consisted of an α-Al matrix with Mg_2Si precipitates and intermetallic phases such as Al(Fe,Mn)Si. No clear relationship was found between the origin of the feedstock and grain morphology. Profiles produced from recycled aluminium showed mechanical properties comparable to those made from primary material. A positive relationship was also observed between hardness and both the Rp0.2 and Rm, with higher hardness corresponding to higher values of both strength parameters. The results indicate that recycled aluminium can be successfully used for the production of aluminium profiles, while the final surface properties are also influenced by profile geometry, local deformation conditions and the applied surface treatment.

Keywords: aluminium extrusion, recycled aluminium, metallography, microstructure, SEM-EDS, microhardness, tensile properties, surface treatment

MECHANICAL COUPLING, MANUFACTURING DISTORTION AND LENGTH EFFECTS IN HTCS THIN-WALLED CFRP PROFILES

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Abstract: This study presents a preliminary investigation of the relationship between tailored mechanical couplings, manufacturing-induced geometric distortions, and the mechanical response of thin-walled CFRP Z-section profiles. Four unconventional 16-ply laminates were selected within a hygro-thermally curvature-stable (HTCS) design framework. The configurations were designed to retain the same principal extensional and bending stiffness components while differing in the type and magnitude of additional coupling terms, providing a controlled basis for assessing the influence of coupling architecture.

The laminates were manufactured from NTPT TP513/34-700/75gsm/36% prepreg using ±22.5° and ±67.5° ply orientations. Material properties used in the Classical Lamination Theory and finite element analyses were determined experimentally. The corresponding A, B and D matrices were calculated to characterise the coupling behaviour of each configuration. Prior to manufacturing, finite element simulations of uniform cooling were performed to verify the expected laminate-level hygro-thermal stability and to assess the tendency for thermally induced warpage under idealised free conditions.

One-metre-long Z-section profiles were subsequently manufactured in an autoclave. Despite the laminate-level HTCS design, measurable geometric distortions were observed in the manufactured components. The profiles were digitised by 3D optical scanning and compared with nominal CAD geometry using full-field deviation maps and transverse-section measurements. Twist angles were determined at several positions along the profile length. Differences between the laminate configurations were evident, with the strongest distortions observed for configurations exhibiting higher coupling intensity. After the profiles were cut into shorter specimens for subsequent compression tests, the apparent magnitude of the longitudinal distortions decreased, indicating that part length is an important factor in the manifestation of manufacturing-induced twist.

Complementary finite element models were developed to separate the principal mechanisms involved. Axial compression simulations demonstrated the mechanical activation of laminate couplings under applied load, whereas process-level models incorporating a rigid tool, contact, cooling and post-demoulding relaxation were used to investigate the origin of manufacturing-induced distortions. The preliminary results indicate that laminate-level hygro-thermal curvature stability does not necessarily guarantee dimensional stability at the structural level. Instead, the final geometry results from an interaction between laminate coupling architecture, component geometry, manufacturing constraints and structural length. These findings provide a basis for

incorporating realistic manufacturing-induced imperfections into subsequent buckling and post-buckling analyses of coupled thin-walled composite profiles.

Keywords: CFRP; mechanical coupling; HTCS laminates; manufacturing-induced distortion; thin-walled profiles; geometric imperfections; 3D optical scanning; finite element analysis

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PRODUCTION ENGINEERING, MANAGEMENT AND QUALITY CONTROL

AN AUDITABLE LARGE LANGUAGE MODEL AND RETRIEVAL-AUGMENTED GENERATION DIGITAL QUALITY TWIN SUPPORTING SIMULATION-BASED VALIDATION AND SAFER DEFECT CONTROL IN INDUSTRY 4.0 AND 5.0 FOR PRODUCTION AND TECHNOLOGY MANAGEMENT

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Abstract: Generative artificial intelligence (GenAI), particularly large language models (LLMs), is increasingly considered for supporting production and technology management. In manufacturing quality engineering, LLMs may reduce the cognitive cost of defect analysis, accelerate root-cause diagnostics, and support quality documentation. Still, they can also generate plausible recommendations that are not grounded in evidence. This creates risks of erroneous process interventions, loss of traceability, and non-compliance with artificial intelligence governance requirements. This paper proposes an auditable LLM-augmented digital quality twin (LDQT) architecture that combines an LLM, Retrieval-Augmented Generation (RAG), a defect-centric digital quality twin, and human-in-the-loop approval. The architecture is evaluated in a discrete-event simulation of a production stream with stochastic process-drift events and three intervention policies: manual, rule-based, and LDQT. The revised computational study includes Monte Carlo analysis, explicit hypothesis testing, and sensitivity analysis. Under the adopted assumptions of 400 replications and 4000 items per replication, the LDQT scenario indicates an approximately 20% lower mean unit cost of quality and downtime than the manual baseline, as well as a higher first-pass yield. These findings should be interpreted as simulation-based evidence of architectural potential, not as proof of practical effectiveness in a real factory. The contribution is methodological: the study defines the Digital Quality Twin concept and provides metrics for balancing efficiency, auditability, and decision safety in industrial GenAI deployments.

Keywords: generative AI, large language models, RAG, digital twin, quality engineering, Industry 4.0, Industry 5.0, human–AI teaming, AI governance, discrete-event simulation

AN INTEGRATED BWM-FUZZY TOPSIS MODEL FOR STEEL STRUCTURE MANUFACTURER SELECTION: A CASE STUDY

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Abstract: The selection of reliable steel structure manufacturers is a critical decision-making problem that directly affects production continuity, project profitability, quality performance, and long-term business cooperation. This challenge becomes particularly significant in engineer-to-order environments, where technical documentation quality, communication efficiency, technological capabilities, and delivery reliability play a key role in project execution. The aim of this study is to develop and apply an integrated Best-Worst Method (BWM) and Fuzzy TOPSIS framework for the evaluation and selection of steel structure manufacturers in an enterprise specialising in steel structure production. First, BWM was employed to determine the relative importance of the evaluation criteria based on expert assessments. Subsequently, Fuzzy TOPSIS was used to rank the analysed manufacturers under conditions of uncertainty and subjective judgement. The proposed framework enables the simultaneous consideration of technical, organisational, and economic criteria affecting supplier performance. The results identify the most influential criteria in the manufacturer selection process and indicate the alternatives that provide the highest potential for long-term cooperation. The findings demonstrate that criteria related to technical documentation quality, communication effectiveness, technological competence, and order profitability have a substantial impact on the final ranking of manufacturers. The study contributes to the supplier selection literature by providing an integrated multi-criteria decision-making framework tailored to the steel structure industry. The proposed approach supports managerial decision-making and offers a practical tool for reducing selection risk and improving the effectiveness of strategic cooperation with manufacturing partners.

Keywords: steel structure manufacturers, supplier selection, Best-Worst Method, BWM, Fuzzy TOPSIS, multi-criteria decision-making

THE LUBLIN R-XIIID AIRCRAFT – HISTORICAL BACKGROUND AND STRUCTURAL CHARACTERISTICS

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Abstract: The presentation will focus on the history of the Plage & Laśkiewicz Mechanical Works in Lublin, a company that played a pivotal role in the development of the Polish aviation industry during the interwar period. It will cover the company's origins and growth, as well as its transition from manufacturing industrial equipment to aircraft production.

Particular attention will be paid to the Lublin R-XIII aircraft—its origins, design process, construction, and the development of subsequent variants. The presentation will also discuss its technical capabilities, its service in the Polish military air force, and its role in the September Campaign of 1939.

Furthermore, the talk will highlight the career of engineer Jerzy Rudlicki—the chief designer associated with the Lublin plant—and the significance of his work for the advancement of Polish engineering. The presentation will conclude with an overview of the contemporary initiative to build a flying replica of the Lublin R-XIII, an effort aimed at preserving and promoting the aviation heritage of Lublin and the surrounding region.

Keywords: Plage & Laskiewicz, aircraft, replica, Poland's first aircraft factory

ENERGY-EFFICIENT UWB LOCALIZATION WITH MULTILATERATION FOR WAREHOUSE ASSET TRACKING

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Abstract: This paper presents a miniaturized, energy-efficient ultra-wideband (UWB) localization platform developed for real-time tracking of assets in warehouse management systems (WMS). The system combines custom, highly integrated hardware with a deterministic position-estimation pipeline. The infrastructure comprises STM32 F7-based anchors with Ethernet and Power over Ethernet connectivity and battery-powered tags based on the nRF52832 microcontroller, environmental sensors, and an accelerometer. Inter-device ranges are acquired through double-sided two-way ranging (DS-TWR). Tag coordinates are then estimated by linearizing the quadratic distance equations and solving the resulting overdetermined system in the least-squares sense. Localization quality is evaluated using the root-mean-square residual between measured and reconstructed anchor-to-tag distances, while the rank of the system matrix is used to verify geometric solvability. The approach requires at least three non-coplanar anchors for three-dimensional positioning and positive range observations. Experimental reconstruction with real measurements was assessed by comparing the estimated tag location with its position in a camera image and a three-dimensional model of the test room. The results demonstrate the feasibility of integrating compact, low-power UWB devices and computationally efficient multilateration into a comprehensive warehouse localization solution. The proposed platform provides a practical foundation for real-time asset visibility, WMS support, and further development of robust positioning algorithms for industrial indoor environments.

Keywords: ultra-wideband, indoor localization, warehouse management systems, double-sided two-way ranging, multilateration, asset tracking

NAR AND LSTM-DEPENDENT PREDICTION FOR EARLY WARNING OF ERRORS IN PROCESS TOMOGRAPHY

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Abstract: Reliable early warning in industrial tomography requires forecasts that capture process dynamics rather than merely extrapolate stationary behavior. This study evaluates how input-window length and feedback updating affect short-term prediction of a nonstationary measurement signal for the predictive layer of a multimodal process-tomography system. A real sequence of 3000 samples, containing steady, declining, and rising regimes with fluctuations lasting 100 to 200 samples, was modeled using nonlinear autoregressive (NAR) and long short-term memory (LSTM) networks. Each model predicted the next 100 samples from base windows of 100, 200, 300, 500, and 1250 observations. Closed-loop forecasting was evaluated both without measurement updates and with updates based on actual observations, while performance was quantified using the root mean square error (RMSE). On steady intervals, NAR slightly outperformed LSTM for the 100- and 200-sample windows, obtaining RMSE values of 0.0068 versus 0.0089 and 0.0066 versus 0.0089, respectively. Under trend changes, LSTM with actual-data updating was more accurate than NAR for the 300-sample window, with RMSE values of 0.0110 and 0.0185. The best overall result was achieved by the updated LSTM using the 1250-sample window, which yielded an RMSE of 0.0050 compared with 0.0143 for NAR. The findings demonstrate that effective early fault warning depends on selecting a history window that spans at least one complete cycle of process variability. Integrating window-aware LSTM forecasts with electrical and ultrasound tomographic reconstruction can strengthen industrial monitoring and support earlier detection of emerging downtime.

Keywords: process tomography, time-series forecasting, long short-term memory, nonlinear autoregressive network, early fault warning, predictive maintenance

TECHNOLOGY MANAGEMENT IN ENERGY ACQUISITION PROCESSES

REVIEW OF THE USE OF EMG SIGNALS IN ENGINE CONTROL SYSTEMS FOR ENERGY EFFICIENCY IMPROVEMENT

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Abstract: Improving the precision of internal combustion engine control–particularly through better matching of engine rotational speed to the conditions under which maximum torque can be generated–enables reliable machine operation while also reducing fuel consumption and harmful exhaust emissions. One promising approach to enhancing engine speed matching involves the use of electromyographic (EMG) signals to predict machine load or to regulate engine speed based on the operator's physiological effort. Operating at lower rotational speeds, when appropriate to the actual load conditions, may contribute to reduced fuel consumption and lower emissions. In the case of wood chippers, existing solutions typically rely on optical sensors located in the feeding channel or on indirect measurements such as the rotational speed of the working mechanism. However, a novel concept is emerging that utilizes EMG signals as a control input, as proposed in patent application No. P.455047. This approach introduces a human-centered control paradigm, in which the operator's neuromuscular activity is directly incorporated into the control loop. Nevertheless, the implementation of such systems requires comprehensive research, including the identification of representative muscle groups, signal processing strategies, and validation of the relationship between EMG activity and machine load. This paper provides an overview of current approaches and outlines the challenges and potential of EMG-based control systems in combustion engine-driven machinery.

Keywords: combustion engine control, adaptive control systems, biomechanical signals, electromyography (EMG), fuel consumption reduction, exhaust emission reduction.

FEASIBILITY STUDY OF SEMG-BASED CONTROL SIGNAL ACQUISITION FOR ENERGY-EFFICIENT ADAPTIVE CONTROL OF AN INTERNAL COMBUSTION ENGINE-POWERED WOOD CHIPPER

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Abstract: Reducing fuel consumption in internal combustion engine-powered working machines requires control strategies that better match engine operation to instantaneous power demand. This feasibility study assessed whether surface electromyography (sEMG) signals from a wood-chipper operator can provide activity information suitable for future anticipatory adaptive control. One healthy male participant performed simulated wood-material feeding using six grip configurations, with 10 repetitions per configuration; eight trials per configuration were retained for analysis. sEMG was recorded from the biceps brachii, flexor carpi ulnaris, extensor carpi ulnaris, and dorsal thumb region, processed using 50-ms RMS smoothing, and evaluated relative to the mean resting RMS level. Threshold ranges were identified for which the signal remained above the threshold for at least 85% of the material-transfer phase. The qualifying ranges depended on both measurement channel and grip configuration. For configuration IV, with the upper limb farther from the chipper, the ranges were +50–450% for the dorsal thumb region, +50–400% for the biceps brachii, +50–250% for the extensor carpi ulnaris, and +50–150% for the flexor carpi ulnaris. Across all configurations, the dorsal thumb region showed the widest ranges, reaching +50–3250% for the one-handed overhand grip, +50–2850% for configuration II, and +50–1800% for configuration III. No single sEMG channel provided equally robust activity detection across all grip conditions, supporting a multi-channel approach. The results demonstrate the feasibility of acquiring operator-derived control information before material reaches the cutting mechanism; however, validation with more participants and during real chipper operation is required before energy-saving or emission-reduction benefits can be established.

Keywords: operator activity detection; electromyographic thresholding; grip configuration; human–machine interaction; anticipatory load prediction; fuel consumption reduction

SMART VILLAGES: SEASONAL VARIATIONS OF RENEWABLE ENERGY IN POLAND

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Abstract: The renewable energy sources may be easily named as the energy of the European future. The ambition of the European Parliament is that renewable energy sources must make up at least 40% of the energy consumed within the EU by 2030. It is not only a political statement, but the reality. In 2023, in Germany, 55 percent of electric energy was created by renewable energy sources, including over 31% produced by wind turbines (both inland and offshore). Poland goes the same path – in 2023, renewables produced 27% of total energy. Recent turbulences in the worldwide market of fossil fuels show clearly that such an approach is a must. The amount of wind-produced energy in Poland has grown over the years, it is not the perfect solution. Its key disadvantage is a variation in time due to the weather changes. It is roughly estimated that the equivalent time of energy generation by a power plant is between 25% and 33%. Our previous studies covered the amount of wind energy over Poland, based on multiannual weather reports. The data show clearly that in a mesoscale, amount of wind energy is moderate, but sufficient to be successfully utilized. However, this energy is not equally distributed in time. It is a well-known fact that the wind speed in winter is higher than in summer, and its variation is the greatest in autumn and spring. Also, the temperature and pressure of the air vary, which leads to changes in wind energy.

Keywords: the usefulness of wind energy, amount of energy, seasonal variation of energy, equivalent time of power plant work

EXPERIMENTAL ANALYSIS OF CURRENT-VOLTAGE CHARACTERISTICS AND STATISTICAL PARAMETERS OF THE EMISSION CURRENT AS A FUNCTION OF TEMPERATURE AND ANODE WORK FUNCTION IN A THERMIONIC ENERGY CONVERTER

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Abstract: In vacuum thermionic energy converters, one of the key parameters is the anode work function and its selection relative to the set cathode work function. This paper presents the results of experimental studies on the influence of temperature and anode work function on the static current-voltage characteristic $I_e=f(U_{k-a})$ of a thermionic energy converter and on the statistical parameters of the electron thermionic emission current I_e at specified operating points of the static characteristic. To ensure repeatable measurement conditions, i.e., conducting the tests with the same anode material, dispenser-type cathodes were used in the design of the converter electrodes. Continuous changes in temperature and anode work function were achieved by controlling the heating power supplied to the anode and using the empirical relationship between work function and temperature.

Keywords: thermionic energy converter, experimental

COMPUTER SIMULATIONS AND APPLICATIONS IN ELECTRICAL ENGINEERING

ADAPTIVE TRAFFIC SIGNAL CONTROL WITH A PPO-TRANSFORMER ARCHITECTURE IN COMPLEX TRAFFIC SYSTEMS

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Abstract: Coordinated traffic signal control in complex urban networks remains a challenging control problem due to strong spatiotemporal coupling between adjacent nodes and dynamically varying traffic demand. An adaptive control framework based on Proximal Policy Optimization (PPO) integrated with a Transformer architecture is proposed to address network-level traffic management across multiple signalized junctions. Traffic conditions are represented as distributed time-series describing aggregated vehicle flows within short intervals. Transformer-based model is used to extract temporal features and capture dependencies between various parts of the network, enabling the control layer to account for propagation effects such as queue spillback and flow interactions. Based on this representation, the PPO agent determines phase transition decisions, balancing local responsiveness with global coordination while satisfying operational constraints. The control objective is formulated at the network level and focuses on minimizing cumulative delay, queue lengths, and congestion while maintaining balanced traffic distribution. The approach is evaluated in the SUMO (Simulation of Urban MObility) simulation environment using a multi-node traffic scenario and compared with a fixed-time control strategy and the adaptive Miller algorithm under identical traffic demand and signal constraints. The results show that the PPO-Transformer framework consistently demonstrates superior performance, adaptability, and scalability, establishing it as the most effective approach for coordinated urban traffic signal control.

Keywords: complex systems, DRL, ITS, PPO, SUMO, transformer

ADAPTIVE INDUSTRIAL TOMOGRAPHIC RECONSTRUCTION THROUGH BIDIRECTIONAL LSTM-GUIDED ENSEMBLE SELECTION

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Abstract: Industrial process tomography requires stable reconstruction from incomplete, noise-sensitive measurements. This study proposes a method-oriented ensemble (MOE) in which a bidirectional long short-term memory (BiLSTM) network selects the best reconstruction method for each electrical impedance tomography (EIT) measurement vector. The framework was assessed using a 200 mm tank with 16 electrodes and variable 20 mm inclusions. MATLAB/EIDORS simulations generated 35,000 three-dimensional training cases. Elastic Net, least-squares linear regression, SVM-based linear regression, support vector machine, and artificial neural network models were trained independently for 2,883 pixels, yielding 14,415 predictors. A two-layer BiLSTM classifier with 128 hidden units per layer processed sequences of 96 voltage measurements and selected the method with the lowest mean root-mean-square error. Adaptive selection increased robustness to disturbances and improved representation of inclusion visibility, shape, number, and position relative to homogeneous reconstruction methods. The concept was also transferred to ultrasound tomography. The framework supports intelligent industrial process monitoring and provides a basis for multimodal EIT-UST reconstruction integrated with autonomous sensor networks.

Keywords: electrical impedance tomography, industrial process tomography, bidirectional LSTM, method-oriented ensemble, adaptive image reconstruction, machine learning, inverse problems, industrial process monitoring

MEASUREMENT-CONSISTENT HYBRID NEURAL RECONSTRUCTION FOR ELECTRICAL IMPEDANCE TOMOGRAPHY

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Abstract: Electrical impedance tomography (EIT) offers non-invasive monitoring of industrial and laboratory reactors, but image reconstruction remains strongly ill-posed because sparse boundary-voltage measurements must be mapped to high-dimensional conductivity distributions. This paper proposes a hybrid deep-learning and physics-informed reconstruction pipeline that combines a transformer-based inverse model, residual Attention U-Net refinement, and optional Plug-and-Play measurement feedback. A normalized 96-element voltage vector is first converted by the primary reconstructor into a logarithmic finite-element conductivity estimate. The estimate is interpolated onto a 128 x 128 grid and refined by an Attention U-Net that preserves the global structure while correcting local artefacts, inclusion boundaries, and contrast. In the optional iterative stage, a differentiable forward surrogate predicts boundary voltages from the current image. The resulting voltage residual drives successive image updates and promotes consistency with the acquired measurements. Qualitative comparisons for three representative EIT cases show progressive improvement from the primary reconstruction through U-Net refinement to Plug-and-Play correction, with clearer inclusion localization, reduced artefacts, improved contrast, and closer visual agreement with the reference conductivity maps. The framework therefore couples the computational efficiency of direct neural inversion with image-domain enhancement and physics-guided consistency control, providing a modular approach to fast and measurement-consistent EIT reconstruction.

Keywords: electrical impedance tomography, inverse problem, transformer, attention U-Net, plug-and-play reconstruction, differentiable forward surrogate, physics-informed deep learning

MULTI-HEAD NEURAL RECONSTRUCTION OF 2D EIT IMAGES FOR INDUSTRIAL REACTOR MONITORING

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Abstract: Electrical impedance tomography (EIT) offers non-invasive, low-cost and high-temporal-resolution monitoring of multiphase processes, but image reconstruction remains constrained by an ill-posed, nonlinear inverse mapping and a large disparity between measurement and image dimensions. This study proposes a multi-head fully connected neural architecture for reconstructing two-dimensional conductivity distributions in industrial reactor cross-sections. The task is formulated as supervised regression from a 96-element boundary-voltage vector to a 2883-element conductivity vector. A shared feature-extraction core feeds 31 parallel output heads, each predicting 93 conductivity values; layer normalization, dropout and L2 regularization are used to stabilize training and limit overfitting. The concatenated head outputs form the final 2D conductivity map. Performance was assessed against a conventional fully connected network with a single output branch using mean squared error (MSE), Pearson correlation coefficient (PCC) and visual inspection of reconstructed maps. In two representative cases, the proposed architecture reduced MSE from 0.0111 to 0.0049 and from 0.0083 to 0.0048, corresponding to reductions of approximately 56% and 42%. PCC increased from 0.6974 to 0.8810 and from 0.8268 to 0.9067, respectively. The multi-head model also yielded more spatially coherent reconstructions, fewer background artifacts and better preservation of the principal conductivity regions. These results indicate that decomposing the high-dimensional output space into localized regression heads improves reconstruction accuracy and stability, providing a promising basis for data-driven EIT monitoring of industrial reactors.

Keywords: electrical impedance tomography, industrial reactor monitoring, inverse problem, multi-head neural network, image reconstruction, supervised regression, conductivity mapping

DIRECT NEURAL RECONSTRUCTION OF URINARY BLADDER IMAGES FROM WEARABLE ELECTRICAL IMPEDANCE TOMOGRAPHY DATA

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Abstract: Electrical impedance tomography (EIT) enables non-ionizing, low-cost and continuous imaging, making it suitable for wearable monitoring of urinary bladder filling. This study investigates a direct neural reconstruction method for a textile EIT system in which conductivity images are estimated from boundary measurements without an intermediate deterministic reconstruction. The proposed measurement concept uses 16 textile electrodes integrated into underwear, while the reconstruction model maps a 96-element EIT vector to a 64 × 64-pixel image. The fully connected multilayer perceptron comprises layers of 96, 256, 512, 1024, 2048 and 4096 neurons and uses ReLU activation, batch normalization and dropout. The model was trained for 50 epochs using the Adam optimizer and mean squared error loss, with the dataset divided into training, validation and test subsets in a 70:15:15 ratio. Evaluation on the independent test set produced an MSE of 0.005, an RMSE of 0.068, a PSNR of 21.44 dB and an SSIM of 0.783. The results show that the direct MLP preserves object geometry while maintaining low reconstruction error, which is relevant to tracking bladder shape and position. The model therefore provides a computationally simple baseline for rapid reconstruction in wearable EIT systems. Future work should validate the method using measurements from the textile prototype and expand the dataset with anatomically representative lower urinary tract scenarios.

Keywords: electrical impedance tomography, urinary bladder monitoring, wearable medical imaging, multilayer perceptron, image reconstruction, textile electrodes

MULTIMODAL NEURAL RECONSTRUCTION FOR HYBRID ULTRASOUND-IMPEDANCE TOMOGRAPHY OF THE LOWER URINARY TRACT

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Abstract: This study presents a multimodal neural reconstruction framework for a hybrid ultrasound-impedance tomograph designed for non-invasive examination of the lower urinary tract. The system integrates a 16-channel electrical impedance tomography (EIT) module with a 32-channel ultrasound tomography (UST) module expandable to 64 channels and supports separate or simultaneous acquisition. Three Multi-Layer Perceptron (MLP) architectures were developed to reconstruct 64 × 64 tomographic images from EIT measurements, UST measurements, and fused EIT-UST features. The EIT and UST models used 96- and 120-element input vectors, respectively. The multimodal model employed parallel modality-specific branches whose 512-dimensional representations were concatenated and processed by a fusion block. The data were divided into training, validation, and test subsets in a 70:15:15 ratio. All models were trained for 50 epochs using the Adam optimizer, a learning rate of 10^{-4}, mean squared error loss, batch normalization, ReLU activation, and dropout. Reconstruction quality was assessed using MSE, RMSE, MAE, peak signal-to-noise ratio (PSNR), and structural similarity index (SSIM), supplemented by visual comparison with reference images. The fused EIT-UST model achieved the best test performance, with an MSE of 0.004227, RMSE of 0.0645, PSNR of 21.86 dB, and SSIM of 0.7860, outperforming both single-modality networks. These results demonstrate that complementary electrical and acoustic measurements improve the fidelity and structural consistency of neural tomographic reconstructions. The proposed approach supports non-invasive, repeatable lower urinary tract assessment and provides a basis for further validation in multimodal bladder monitoring.

Keywords: electrical impedance tomography, ultrasound tomography, multimodal imaging, image reconstruction, multi-layer perceptron, neural networks, lower urinary tract, urinary bladder

MULTIMODAL EITS AND OPTICAL SENSING FOR NON-INVASIVE GLUCOSE MONITORING

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Abstract: This study presents a modular hardware platform for investigating non-invasive glucose monitoring through electrical bioimpedance and glucose-induced osmotic phenomena, complemented by optical near-infrared spectroscopy and photoplethysmography (NIRS/PPG). The measurement principle does not rely on direct electrical detection of glucose molecules. Instead, it exploits water redistribution between intracellular and extracellular compartments caused by changes in osmolarity. The resulting variations in cell geometry, membrane capacitance, and extracellular conduction paths produce frequency-dependent shifts in tissue impedance. The proposed platform implements Electrical Impedance Tomography Spectroscopy (EIT-S) for controlled current excitation, voltage acquisition, and impedance analysis over a selected frequency range. Its modular architecture comprises a signal-generation stage, analog front-end, data-acquisition circuitry, and an STM32WBA-based control board responsible for processing and wireless transmission. A dedicated sensing board integrates gold-plated electrodes, optical emitters, and reflected-light detectors, enabling electrical and optical signals to be acquired from the same tissue region. Measurement data are transmitted via Bluetooth Low Energy to a mobile application that functions as both the user interface and a local node of a distributed diagnostic system. The developed device constitutes an experimental testbed for studying correlations among glucose concentration, osmotic effects, bioimpedance spectra, and optical features. Its multimodal architecture provides a basis for future calibration, feature-fusion, and validation studies toward comfortable and continuous glucose monitoring.

Keywords: non-invasive glucose monitoring, electrical bioimpedance spectroscopy, EIT-S, osmotic phenomena, NIRS, PPG, multimodal sensing, biomedical instrumentation, bluetooth low energy