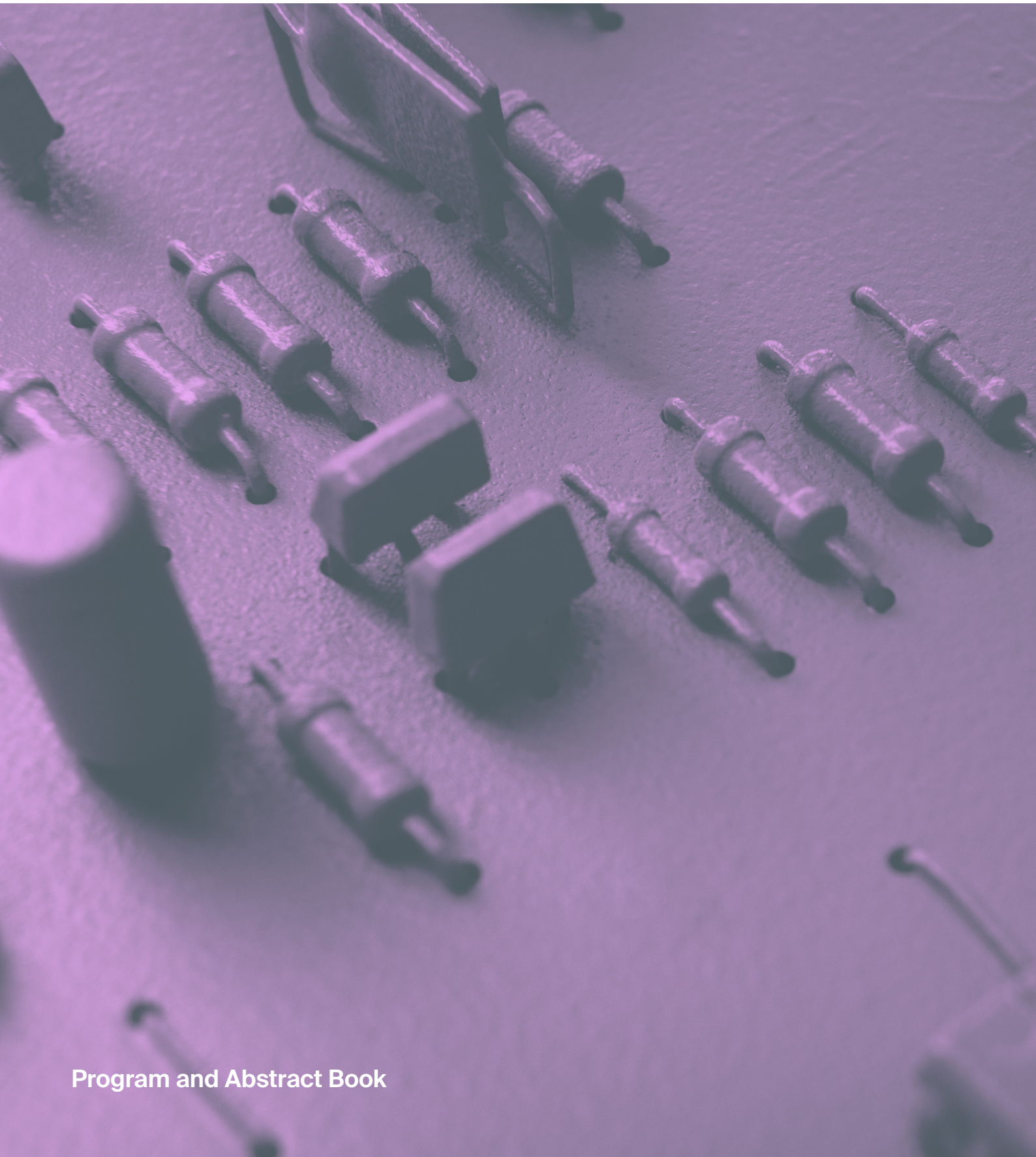
CSAN 2026 Conference

The 1st International Online Conference on Sensor and Actuator Networks

9–10 July 2026 | Online



Program and Abstract Book

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The 1st International Online Conference on Sensor and Actuator Networks

9–10 July 2026 | Online

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Prof. Adnan M. Abu-Mahfouz
Prof. Jordi Mongay Batalla
Prof. Jianwei Niu
Prof. Pascal Lorenz
Prof. Sye-Loong Keoh

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Welcome from the Chair

Dear colleagues,

It is our pleasure to invite you to join the 1st International Online Conference on Sensor and Actuator Networks, which will be hosted online from 9 to 10 July 2026.

This conference will present the latest studies in sensor and actuator network-related research in the fields of healthcare, smart agriculture, industry, mobile systems, intelligent transportation, manufacturing, smart cities, and engineering. The goal is to highlight the status, challenges, and opportunities as well as future trends in sensor and actuator network engineering. CSAN 2026 will present the state-of-the-art sensor and actuator networks related to the following topics:

S1. Industry 4.0 and embedded wireless sensor/actuator systems
S2. Blockchain technologies and Internet-of-Things-based WSAN
S3. WSAN and next-generation networks (5G, 6G, etc.)
S4. Applications of WSAN in agriculture, vehicle, wearable sensors, smart cities, manufacturing, mobile systems, and health and medical care
S5. Big Data, Computing and Artificial Intelligence

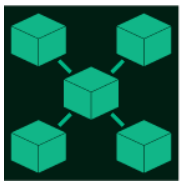
CSAN 2026 will enable you to share and discuss your most recent research findings with the worldwide vibrant community of scientists and engineers in the field.

CSAN 2026 will make your presentation accessible to hundreds of researchers worldwide, with the active engagement of the audience in question-and-answer sessions and discussion groups that will take place online.

Submitted abstracts will be reviewed by the conference committee. All accepted abstracts will be available online in Open Access form on Sciforum.net during and after the conference. Following the conference, selected contributions will be invited for submission to the JSAN journal (ISSN: 2224-2708, Impact Factor: 4.8), with a 15% discount on the publication fee.

We hope you will join us, present your work at CSAN 2026, and be part of this exciting online event.

Prof. Dr. Lei Shu
Conference Chair
Nanjing Agricultural University, Nanjing, China; University of Lincoln, Lincoln, UK



Journal of
Sensor and Actuator Networks
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Journal of Sensor and Actuator Networks (ISSN 2224-2708) is an international open access journal on the science and technology of sensor and actuator networks. It publishes regular research papers, reviews (including comprehensive reviews on complete sensor and actuator networks), and short communications. Our aim is to encourage scientists to publish their experimental and theoretical results in as much detail as possible. There is no restriction on the maximum length of the papers. The full experimental details must be provided so that the results can be reproduced. There are, in addition, unique features of this journal:

- Manuscripts regarding research proposals and research ideas will be particularly welcome.
- Electronic files and software regarding the full details of the calculation and experimental procedure, if unable to be published in a normal way, can be deposited as supplementary material.

Impact Factor: 4.8 (2025); 5-Year Impact Factor: 4.0 (2025)

Session Chairs

Prof. Adnan M. Abu-Mahfouz

Council for Scientific and Industrial Research (CSIR), Pretoria, South Africa

Prof. Jordi Mongay Batalla

Institute of Telecommunications and Cybersecurity, Warsaw University of Technology, Warszawa, Poland

Prof. Jianwei Niu

School of Computer Science and Engineering, Beihang University, Beijing, China

Prof. Pascal Lorenz

University of Haute-Alsace, Mulhouse and Colmar, France

Prof. Sye-Loong Keoh

School of Computing Science, University of Glasgow, Glasgow, UK

Event Committee

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Asst. Prof. Tariq Shahzad
Department of Computer Engineering, COMSATS University Islamabad, Pakistan

Professor Zhangbing Zhou
School of Information Engineering, China University of Geosciences, Beijing, China

Invited Speakers

Dr. Daniel Ramotsoela

Department of Electrical Engineering, University of Cape Town (UCT), Cape Town, South Africa

Asst. Prof. Ng Pai Chet

Singapore Institute of Technology (SIT), Singapore

Prof. Dr. Shui Yu

School of Computer Science in the Faculty of Engineering and Information Technology, University of Technology Sydney, Sydney, Australia

Speakers of Journal Published Paper

Dr. Anastasia Bougea

School of Electrical and Computer Engineering, National Technical University of Athens, Athens, Greece

Professor Boon-Chong Seet

Department of Electrical and Electronic Engineering, Auckland University of Technology, Auckland, New Zealand

Dr. Ghazanfar Ali Safdar

School of computing, Engineering and Creative Industries, University of Bedfordshire, Luton, UK

Prof. Dr. Hovannes Kulhandjian

Electrical and Computer Engineering, California State University, Fresno, CA, USA

Prof. Dr. Mohammad Hammoudeh

King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia

Dr. Masood Ur Rehman

James Watt School of Engineering, University of Glasgow, Glasgow, UK

Dr. Qasem Abu Al-Haija

Jordan University of Science and Technology (JUST), Irbid, Jordan

Dr. Sushank Chaudhary

School of Computer, Guangdong University of Petrochemical Technology, Maoming, China

Dr. Tapiwa Chiwewe

Council for Scientific and Industrial Research, South Africa

Program at a Glance

Date/Time (CEST)	DAY 1 (9 July)	DAY 2 (10 July)
Morning (9:00)	**S1.** Industry 4.0 and embedded wireless sensor/actuator systems **S5.** Big Data, Computing and Artificial Intelligence	**S3.** WSAN and next-generation networks (5G, 6G, etc.) **S2.** Blockchain technologies and Internet-of-Things-based WSAN
Lunch Break		
Afternoon (14:00)	**S4.** Applications of WSAN in agriculture, vehicle, wearable sensors, smart cities, manufacturing, mobile systems, and health and medical care	

CSAN 2026 Program

DAY 1 Program Details (9 July)

S1: Industry 4.0 and embedded wireless sensor/actuator systems
S5. Big Data, Computing and Artificial Intelligence

Date: 9 July 2026 (Day 1) Morning
Time: 9:00 (CEST, Basel) | 08:00 (BST, UK) | 15:00 (CST Asia, Beijing)

Time (CEST)	Time (CST)	Speakers	Title
09:00–09:10	15:00–15:10	**Prof. Dr. Lei Shu** Event Chair	Opening Talk
09:10–09:20	15:10–15:20	**Prof. Adnan M. Abu-Mahfouz** Session 1 Chair	Session Introduction
09:20–09:50	15:20–15:50	**Dr. Daniel Ramotsoela** Invited Speaker	Zero-Trust Architecture: Redefining Network Security for Industrial Cyber-Physical Systems
09:50–10:25	15:50–16:25	**Dr. Tapiwa Chiwewe** Invited Speaker	From Sensing to Action: Foundation Models, Edge Intelligence, and Agentic AI for Autonomous Industrial Systems
10:25–11:05	16:25–17:05	**Prof. Jianwei Niu** Session 5 Chair	Session Introduction Opening Speech Title: Embodied AI Operating System for Robotics-Thoughts and Practice
11:05–11:40	17:05–17:40	**Prof. Shui Yu** Invited Speaker	Mathematical Artificial Intelligence for Networking and Communications
11:40–12:15	17:40–18:15	**Dr. Anastasia Bougea**	Multimodal Explainable Artificial Intelligence (XAI) Applied to Parkinson's and Alzheimer's Diseases

Lunch Break (12:05–15:00) (CEST)

S4. Applications of WSAN in agriculture, vehicle, wearable sensors, smart cities, manufacturing, mobile systems, and health and medical care

Date: 9 July 2026 (Day 1) Afternoon
Time: 15:00 (CEST, Basel) | 14:00 (BST, UK) | 21:00 (CST Asia, Beijing)

Time (CEST)	Time (CST)	Speakers	Title
15:00–15:40	21:00–21:40	**Prof. Sye-Loong Keoh** Session 4 Chair	Session Introduction Opening Speech Title: Smart Public Transportation in the age of Connectivity x AI x IoT
15:40–16:15	21:40–22:15	**Prof. Ng Pai Chet** Invited Speaker	Multi-Modal Human Activity Recognition: Federated Learning Across Heterogeneous Physiological and Wireless Signal
16:15–16:45	22:15–22:45	**Dr. Masood Ur Rehman**	ForestWatch: Observing, Responding and Predicting the Deforestation Events using Wireless Sensors
16:45–17:15	22:45–23:15	**Dr. Sushank Chaudhary**	From Sensors to the Metaverse: Bridging the Physical and Virtual Worlds
17:15–17:45	23:15–23:45	**Prof. Dr. Hovannes Kulhandjian**	Advancing AI and Robotics: Innovations in AgTech, Intelligent Transportation, and Assistive Technologies

DAY 2 Program Details (10 July)

S3. WSAN and next-generation networks (5G, 6G, etc.)
S2. Blockchain technologies and Internet-of-Things-based WSAN

Date: 10 July 2026 (Day 2) Morning
Time: 9:00 (CEST, Basel) | 08:00 (BST, UK) | 15:00 (CST Asia, Beijing)

Time (CEST)	Time (CST)	Speaker	Title
9:00–9:05	15:00–15:05	**Prof. Jordi Mongay Batalla** Session 3 Chair	Session Introduction
9:05–9:35	15:05–15:35	**Prof. Boon-Chong Seet**	Reconfigurable intelligent surfaces in underwater wireless communication: Challenges and future directions
9:35–10:05	15:35–16:05	**Dr. Ghazanfar Ali Safdar**	Bandwidth Conscious Interference Mitigation in D2D Underlay 5G Networks
10:05–10:35	16:05–16:35	**Dr. Qasem Abu Al-Haija**	Security of Critical Infrastructure Cyber-Physical Systems (CPS)
10:35–11:15	16:35-–17:15	**Prof. Pascal Lorenz** Session 2 Chair	Session Introduction Opening Speech Title: Architectures of Next Generation Wireless Networks
11:15–11:45	17:15–17:45	**Prof. Dr. Mohammad Hammoudeh**	Enhancing Cybersecurity Resilience in Operational Technology for the Energy Sector: The Role of AI-Driven Anomaly Detection
11:45–11:55	17:45–17:55	**Prof. Dr. Lei Shu** Event Chair	Closing Speech

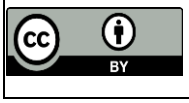
Session 1. Industry 4.0 and Embedded Wireless Sensor/Actuator Systems

sciforum-182702: A Bibliometric and Thematic Analysis of Hybrid AI for Predictive Maintenance and Prognostics & Health Management in Cyber-Physical Manufacturing Systems (2018–2025)

Said AMGHAR, Abdellah Azmani, Benaissa Amami, Kamal Reklaoui

[1] Intelligence Automation & Biomedical Genomics Laboratory (IABL), Abdelmalek Essaadi University, Tangier, Morocco

Predictive Maintenance (PdM) and Prognostics and Health Management (PHM) are central to Industry 4.0 and Industry 5.0, where intelligent, connected, and human-centered production systems leverage AI, Big Data, IoT, CPS, edge computing, blockchain, and digital twins to enhance reliability, availability, and decision-making. This study presents a combined bibliometric and state-of-the-art analysis of hybrid AI approaches in PdM/PHM, using merged data from Web of Science and Scopus, analyzed with Bibliometrix and VOSviewer, following the PRISMA framework. The analysis emphasizes annual scientific production, source and country contributions, keyword co-occurrence, thematic evolution, and conceptual structure, complemented by a critical review of top-cited documents to extract architectures, methodological trends, and limitations. Several families of hybrid AI architectures are identified, including feature engineering combined with deep learning, CNN-LSTM or CNN-GRU models, autoencoder-based transfer learning, digital twin-assisted deep learning, seq2seq with attention mechanisms, and ensemble learning approaches. The research focuses on predictive maintenance, fault diagnosis, and smart manufacturing, while gaps remain in CPS integration, real-time decision-making, robustness to domain shifts, data scarcity, explainability, and industrial validation, as many studies rely on public datasets. By linking bibliometric insights with technical depth, mapping hybrid AI architectures to PHM functions, and highlighting concrete research gaps such as uncertainty-aware RUL prediction, edge deployment, multi-modal data fusion, and explainable models, this work provides a forward-looking perspective and positions the study as a critical, actionable roadmap for advancing hybrid AI in PdM/PHM within Industry 4.0 contexts.



sciforum-183671: Bayesian Structural State Tracking from Sparse Sensor Data Using Sequential Gaussian-Process Updating in Experimental Bridge Load Tests

Olubunmi Emmanuel Ogunleye[1], Abiola Usman Adebanjo[2], Abiodun Victor Alagbada[3], Adejoke Vera Jegede[4]

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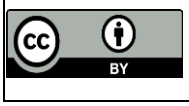
[2] Deaprtment of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia
[3] Institute of Structural Mechanics, Bauhaus Universitat Weimar, 99423 Weimar, Germany
[4] Department of Civil and Environmental Engineering, Osun State University, Osogbo, Nigeria

Sparse sensing remains a major limitation in bridge structural health monitoring, particularly when load-test data are interpreted without explicit uncertainty quantification. This paper proposes a sequential Gaussian-process Bayesian updating framework for tracking the evolving structural state of a prestressed concrete bridge from sparse measurements collected during a full-scale experimental load test. The measured response includes force, strain, temperature, local displacement, and laser-based deflections recorded over progressive displacement-controlled loading stages ranging from 5 mm to 60 mm. For each stage, a probabilistic deflection field is reconstructed from the available sensor data, while posterior information from previous stages is propagated to subsequent stages to represent the continuity of structural response under increasing demand. From the inferred posterior response fields, uncertainty-aware structural health monitoring indicators are derived, including compliance evolution, curvature concentration, and response-drift measures between loading stages. A sensor sensitivity analysis is further conducted to quantify the contribution of individual measurement locations to prediction accuracy and posterior uncertainty. Model performance is evaluated through reconstruction accuracy, posterior consistency, and credible-interval calibration. The results show the potential of sequential Bayesian inference to convert sparse experimental load-test data into an interpretable probabilistic description of structural behavior, supporting uncertainty-aware assessment, structural model updating, and future digital-twin integration.



sciforum-177129: Experimental Validation of the BlueSkyTec Post-Quantum Cybersecurity Defence Mechanism

Ebtesam J. Alqahtani[1], Nouf J. Alqahtani[2], Mohammad H. Hammoudeh[1]

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[2] Department of Control & Instrumentation Engineering, King Fahd University of Petroleum & Minerals, Dhahran 31261, PO Box 5051, Saudi Arabia

Industrial Control Systems (ICS) form the backbone of critical infrastructure sectors. Their increasing interconnection with enterprise networks expanded the Operational Technology (OT) attack surface while maintaining strict real-time and safety constraints. Existing cybersecurity mechanisms relied primarily on perimeter-based defences and computationally secure cryptography, which introduced operational limitations and remained vulnerable to future quantum threats. A gap therefore existed for a defence architecture that preserved deterministic operation while enabling post-quantum resilience.

In this study, we experimentally validated a post-quantum cybersecurity defence mechanism called BlueSkyTec Technology (BST). The technology integrates Hardware-Rooted Cryptographic Identity (HRCI), and information-theoretically secure encryption within a unified identity-centric model. BST was selected as it represents a hardware-rooted, One-Time-Pad (OTP) based key-distribution architecture capable of meeting deterministic ICS timing constraints that conventional NIST standardised post-quantum algorithms cannot satisfy. Unlike zero-trust architectures, which address lateral movement at the network-policy level, BST provides cryptographic resilience against harvest-now-decrypt-later threats while maintaining microsecond-scale latency compatible with Programmable Logic Controllers (PLCs) cycles.

BST architecture consists of:

The HRCI enabling device authentication bound to tamper-resistant hardware trust anchorsThe OTP encryption supported by quantum-derived entropy, providing information-theoretic confidentialityIdentity-based communication enforcement in which each endpoint is authenticated using a HRCI derived from Physically Unclonable Function (PUF) or secure-element–bound key materialNetwork policy permitting communication only among provisioned and verified HRCI identities, thereby enforcing an authorized identity space and implementing a zero-trust model across IT and OT boundaries

The architecture was evaluated within a simulated internet-connected ICS testbed representing modern critical infrastructure deployments. The environment comprised PLCs, a SCADA server, an engineering workstation, a Human Machine Interface (HMI), a historian server, and logically segmented IT and OT network zones, designed to replicate deterministic PLC and HMI communication cycles and UDP-based industrial traffic. Adversarial scenarios were derived from the MITRE ATT&CK for ICS framework to ensure realistic and reproducible threat coverage. Experimental evaluation considered both cybersecurity functional and non-functional performance. Functional performance included confidentiality, integrity, anti-tampering, and authentication. Non-functional metrics measured control-loop latency, throughput, environmental suitability, and interoperability.

Structured attack campaigns were designed to model realistic adversarial behaviours using controlled packet-level simulations. This included packet injection to emulate falsified or unexpected traffic patterns and unauthorized command attempts representing efforts to influence PLC behaviour without valid authentication. Additional scenarios assessed the system's ability to maintain confidentiality and authenticity of transmitted packets, ensuring that unverified identities could not access or impersonate trusted endpoints. Integrity experiment evaluated whether the system could detect and prevent unauthorised modification of packet contents during transmission. Finally, controlled tampering simulations were performed to verify that the

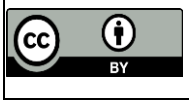
defence mechanisms correctly identified and blocked attempts to alter, replay, or manipulate ICS traffic in alignment with MITRE ATT&CK for ICS techniques such as T0827 - Spoof Reporting Messages, T0820 - Manipulation of Control, and T0851 - Man-in-the-Middle.

Experimental results demonstrated comprehensive detection and prevention across evaluated attack scenarios. The HRCI mechanism prevented unauthorized lateral movement between IT and OT zones even when valid credentials were compromised because communication attempts lacking authenticated HRCI were automatically rejected at the policy enforcement layer. PLC logic integrity validation blocked malicious configuration uploads prior to execution, while the anomaly detection layer identified protocol and process deviations with high accuracy and negligible false positives. Across all adversarial scenarios executed within the simulated internet-connected ICS testbed, the system consistently demonstrated strong functional and non-functional performance. Quantitatively, the system passed all confidentiality, integrity, authentication, and anti-tampering tests, correctly identifying and blocking attempts to alter, replay, or manipulate UDP-based industrial traffic. Non-functional performance also remained within operational limits; the latency stayed inside deterministic PLC–HMI timing requirements, throughput remained stable, and no measurable degradation in availability, environmental suitability, interoperability, or process-state stability was observed. Entropy analysis confirmed high-quality randomness, and key-uniqueness evaluation showed no statistical duplication across devices. The use of OTP-based encryption eliminated reliance on computational hardness assumptions, providing long-term resilience against anticipated quantum-era cryptanalytic threats.

Our key contributions are:

Evaluate the BST architecture and its underlying security modelProvide insights into the effectiveness of BST, deterministic security, and critically assess their suitability and limitations within ICS environments

Initial results demonstrated the feasibility of deploying post-quantum, identity-centric security mechanisms in safety-critical industrial environments. BST architecture proved to provide an effective ICS cybersecurity by addressing both present operational threats and emerging quantum risks while preserving system reliability and real-time performance.

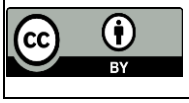


sciforum-174604: Neuromorphic Event Sensor-Based Optical Flow Estimation with Occlusion Handling for UAV Perception in Industry 4.0 Inspection Systems

Ibrahim Akanbi, Michael Ayomoh

[1] Department of Industrial and Systems Engineering, University of Pretoria, Pretoria 0002, South Africa

Unmanned Aerial Vehicles (UAVs) require accurate and robust motion estimation to enable autonomous navigation in complex environments. Event cameras sensor, a bio-inspired sensors capturing high-temporal-resolution brightness changes, provide an attractive vision modality under challenging conditions such as high dynamic range and rapid motion. However, event-based sensor optical flow estimation remains challenging due to noise, sparsity, and occlusions inherent in event data, limiting UAV performance. In this work, we present a novel event-based sensor optical flow estimation framework that integrates a lightweight OcclusionNet to pre-emptively mask occluded and noisy events, enhancing the downstream Contrast Maximization (CM) optimization. Our approach extends classical CM by incorporating occlusion-aware data filtering, reducing overfitting, improving convergence, and preserving the sharpness of the image of warped events (IWE). Quantitative evaluation demonstrates our method achieves competitive end-point errors (EPE ≈ 1.7 pixels) and flow angular errors, closely matching ground-truth flow warping loss metrics, while eliminating large error outliers. The model was evelauted on a 1th Gen Intel Core i7-13700 with 32GB RAM, achieving approximately 0.09 seconds per frame on the MVSEC indoor_flying sequences. Qualitatively, our occlusion-aware flow yields sharp IWEs and robust performance under complex motions and lighting, showing strong potential for UAV tasks. This work highlights the benefits of integrating occlusion reasoning into event-based flow estimation, paving the way for reliable and efficient sensory for UAV perception in industry 4.0 inspection system.



Session 2. Blockchain Technologies and Internet-of-Things-Based WSAN

Session 3. WSAN and Next-Generation Networks (5G, 6G, etc.)

sciforum-183583: OpenWrt-Oriented Cooperative Multi-AP Wi-Fi Sensing with Reliability-Aware Fusion and QoS-Bounded Measurement Control

Volodymyr Pavlenko

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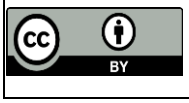
Introduction: Cooperative Wi-Fi sensing across multiple access points is attractive for indoor monitoring because spatial diversity can reduce blind spots, stabilize detection when one wireless link fades, and move sensing closer to realistic controller-managed deployments than single-link laboratory demonstrations. In practice, however, multi-AP sensing is difficult to reproduce because different access points expose different chipsets, firmware branches, capture tools, packet-delivery behavior, timing quality, and sensing modalities. Prior cooperative Wi-Fi sensing work already shows the value of multi-link CSI fusion, AP-side CSI collection workflows such as CSI Sniffer, CSI transport reduction by compression methods such as EfficientFi and RSCNet, and coexistence-aware sensing traffic control in Slim-Sense and UniFi-style controller-managed operation. These studies solve important parts of the problem, but they usually treat fusion accuracy, measurement transport, and communication coexistence as separate concerns. They also do not define a single commodity-AP protocol that states how unreliable links are handled, how sensing remains inside controller-visible service budgets, and what another group must log to repeat the same policy. This work addresses that gap for OpenWrt-oriented deployments by defining a reproducibility-oriented workflow that makes per-link reliability assessment, controller-visible quality-of-service constraints, and a reproducibility manifest explicit in one protocol.

Methods: The workflow assumes N OpenWrt access points or OpenWrt-compatible AP nodes and one central coordinator reachable through the management plane. Each access point runs a lightweight local agent that converts raw Wi-Fi measurements into compact descriptors derived from received signal strength and, where hardware support exists, channel state information, while also reporting packet acceptance, temporal stability, timestamp consistency, and modality availability. The coordinator assigns a reliability score to each link, aggregates local descriptors with reliability-aware weighting, and exposes explicit measurement-budget controls over the active access-point subset, sensing modality, capture rate, and burst duration under configured limits on sensing airtime share, protected-flow throughput loss, and protected-flow latency inflation. For early validation, the protocol was instantiated in a small indoor setup using ESP32-C5 and ESP32-S3 sensing nodes, a primary prplOS-compatible dual-band AP node on 5 GHz channel 36, an additional 5 GHz helper AP node, a dedicated 2.4 GHz helper AP on channel 6, Linux helper nodes, UDP CSI-summary capture, feature-window export, controller-decision logs, and SSH byte-stream protected-traffic traces collected by a laptop coordinator with two Wi-Fi adapters. The block protocol included warm-up, empty-room, static-presence, and motion periods. Each run also records a minimum manifest covering access-point role, chipset or sensing node, firmware or tool profile, radio configuration, sensing policy, topology role, synchronization evidence, and protected-traffic profile. The same run files are intended to be sufficient for a second laboratory to reconstruct the topology, radio state, sensing mode, controller policy, and protected-flow context without relying on hidden operator notes.

Results: The current result is a concrete workflow specification and evaluation contract rather than a finished large-scale benchmark. The method is designed to turn heterogeneous access-point-side measurements into a common coordinator-facing representation, proposes an operational rule for down-weighting or excluding unreliable links before fusion, and makes sensing and communication coexistence measurable through controller-side budget variables. The early validation had two limited purposes: to check that the capture/control evidence can be logged on hardware, and to sanity-check the fusion rule before larger experiments. In the indoor setup, the workflow captured live CSI-summary streams, feature windows, controller decisions, timing

evidence, selected-node information, and protected-traffic traces under the stated block protocol. A synthetic three-link sanity-check comparison then illustrates the intended trade-off: reliability-weighted fusion raises a normalized stability index from 0.68 to 0.79 while keeping protected-flow throughput loss within a 3% service budget, increasing from 2.4% to 2.7%. This numeric example is not presented as a large-scale detection-accuracy result; it is used to verify that the proposed budget and reliability variables behave coherently before full testbed evaluation. The hardware pass also checked a practical failure mode emphasized by the workflow: if a link lacks usable CSI or shows unstable packet acceptance, the coordinator can keep that link visible in the manifest while excluding it from the fused descriptor. This keeps negative evidence available for audit instead of silently dropping failed AP observations. The workflow also defines a minimum manifest that reduces ambiguity during reproduction on another OpenWrt-oriented testbed.

Conclusions: The proposed workflow provides a structured and falsifiable deployment protocol for cooperative Wi-Fi sensing on commodity access-point infrastructure under realistic controller constraints. Relative to prior cooperative Wi-Fi sensing, CSI capture, compression, and coexistence-aware traffic-control studies, its practical value is to combine reliability-aware fusion, QoS-bounded measurement control, and reproducibility reporting in one OpenWrt-oriented baseline. This gives future OpenWrt testbed studies a common reference for what to log, what to budget, and how to compare cooperative policies fairly. The next step is broader quantitative experimentation on a real multi-access-point OpenWrt platform for binary presence or localization-style tasks under fixed service budgets. Accordingly, the work is positioned as a repeatable control and reporting baseline; later experiments will quantify task accuracy and service degradation under broader OpenWrt testbed conditions.



sciforum-162450: Security of Critical Infrastructure Cyber-Physical Systems (CPS)

Qasem Abu Al-Haija

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Critical infrastructure systems—such as power grids, transportation networks, water treatment facilities, and industrial automation platforms—are increasingly interconnected, automated, and data-driven. This evolution has transformed them into complex cyber-physical systems (CPS) with tightly coupled digital and physical components. While this integration enhances efficiency and real-time control, it also exposes critical assets to new classes of cyber threats capable of causing systemic disruption, physical damage, or large-scale service failures. This talk presents a CPS-oriented perspective on securing critical infrastructure, emphasizing the unique risks that emerge from sensing, actuation, communication, and control loops. I will discuss recent attack patterns—including sensor spoofing, command injection, and coordinated cyber-physical attacks—along with the cascading effects these threats can trigger across dependent subsystems. The presentation outlines a structured methodology for threat modeling in CPS, highlights detection and response challenges, and showcases practical strategies leveraging AI-driven analytics, resilient control design, and intrusion-tolerant architectures. The session aims to provide a holistic understanding of how modern critical infrastructures can be hardened against next-generation cyber-physical adversaries while maintaining safety, reliability, and mission-critical performance.

Session 4. Applications of WSAN in Agriculture, Vehicle, Wearable Sensors, Smart Cities, Manufacturing, Mobile Systems, and Health and Medical Care

sciforum-165568: Advancing AI and Robotics: Innovations in AgTech, Intelligent Transportation, and Assistive Technologies

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Autonomous systems are rapidly moving from lab prototypes to real deployments across farms, cities, and community spaces. This talk surveys practical AI-robotics pipelines—perception, planning, control, and human-in-the-loop design—that my group has translated into working field systems. In AgTech, we'll discuss modular platforms for fruit harvesting, precision spraying, and pollination, combining edge vision (lightweight detectors on Jetson), robust actuation (CoreXY mechanisms, 6-DoF arms), and data-driven operations. In civil infrastructure and transportation, we will focus on AI-powered bridge and roadway inspection—vision/LiDAR-based defect detection, surface-distress mapping, and structural-condition scoring—as well as road-user safety through vehicle, cyclist, and pedestrian detection with near-miss analytics for proactive hazard mitigation. For assistive technologies, we'll cover CrossBot, a smart crossing-assist robot, and ongoing work integrating low-visibility sensing (IR/radar/audio fusion) and brain–computer interface (BCI) concepts to expand accessibility. This includes results stemming from my U.S. patent on low-visibility human/animal detection using multimodal sensing, and lessons learned when hardening research prototypes for real environments. Across these domains, I'll share insights on system architecture, model selection (from classical computer vision to compact deep nets), domain shift and on-device adaptation, and workforce development through student-centered field deployments—closing with an outlook on scalable, standards-aligned deployments and academia–industry–community collaboration.

sciforum-181737: Development of an Intelligent Edge-Computing Algorithm for the Prediction of Workforce Productivity and Physiological Load in Manual Material Handling

Adinife Patrick Azodo[1], Salami Olasunkanmi Ismaila[1], Sidikat Ibiyemi Kuye[1], Olawale Usman Dairo[2]

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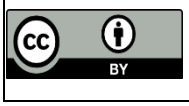
Manual material handling remains a physically demanding activity with significant implications for workforce productivity and occupational health. While laboratory-based assessments exist, field-ready systems for real-time monitoring at the point of work remain limited. This study developed an edge-based predictive framework for estimating workforce productivity and physiological load without cloud dependency. The system integrates wearable sensors, including heart rate monitors, pulse oximeters, sphygmomanometers, and goniometers, with a locally deployed multivariate regression model designed for low computational overhead and minimal latency. Following ethical approval and informed participant consent, the framework was validated using 390 male participants aged 20–39 years. Participants performed lifting, lowering, and carrying tasks using wheelbarrows, carts, concrete blocks, and head pans under field and staircase conditions. Physiological and environmental variables were acquired at a sampling frequency of 1 Hz and processed through a GUI-embedded predictive algorithm. The system estimates energy expenditure (EE), maximal oxygen uptake (VO_2max), and task-specific work capacity. Experimental validation showed prediction errors of 7.39%, 8.54%, and 9.89% for VO_2max, energy expenditure, and workforce productivity, respectively, indicating strong agreement with measured values. The framework demonstrates the potential of edge-enabled wearable sensing systems for real-time ergonomic assessment, occupational risk reduction, and productivity optimization in manual labor environments.

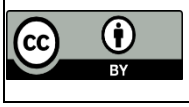


sciforum-171450: ForestWatch: Observing, Responding and Predicting the Deforestation Events using Wireless Sensors

Masood Ur Rehman

[1] James Watt School of Engineering, University of Glasgow, UK

The world today is striving to be smarter through the influx of innovative technologies. Communication and sensing devices/systems are a vital part of these technologies with applications beyond their usual domain and playing a crucial role in every aspect of our lives including healthcare, automation, transport, weather, education, entertainment, and security. Uninhibited industrialization, urbanisation and fulfilment of an over-populated planet has brought upon us a climate emergency. Deforestation through depletion of the tree crown cover and degradation of tree health caused by over-exploitation, repeated fires, or diseases is reckoned as one of the major drivers behind catastrophic climate changes. It also inflicts long-term economic losses due to limited natural resources, soil erosion, increased flooding, drought, and a domino of unfavourable effects in terms of ecosystem and public health. This talk unfolds the potentials of using a low-cost, autonomous, real-time monitoring and response system utilising intelligent wireless sensor networks and holistic implementation of Internet-of-Things to combat deforestation and avoid a fast-looming climatical calamity.



sciforum-183178: Hip mobility is a clinically meaningful driver of pain reduction in CNLBP: Evidence from IMUs and Markerless Systems Analysis – A Pilot Study

Elpida Foti[1], Athanasios Triantafyllou[1, 2], Nefeli Maria Tsirmpini[1], Panagiotis Koulouvaris[1], Charilaos Tsolakis[3], Apostolos Z. Skouras[1], Panagiota Papadea[4], Maria Kyriakidou[2], Sophia Stasi[2], Panagiotis Gkrilias[2], Georgios Papagiannis[1, 2]

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Background: Chronic nonspecific low back pain (CNLBP) is associated with altered lumbopelvic mechanics and reduced hip mobility [1,2]. Although hip motion deficits have been linked to persistent symptoms [3], the relationship between changes in hip flexion and clinical outcomes during rehabilitation remains incompletely understood. In parallel, markerless motion capture systems have emerged as accessible tools for movement assessment [4], although their agreement with established clinical measurement approaches requires further investigation.

Objective: To investigate the association between changes in active hip flexion and pain intensity during rehabilitation in individuals with CNLBP and to examine the agreement between a machine learning–based markerless motion capture system and inertial measurement units (IMUs).

Methods: Eleven participants with CNLBP completed a 6-week therapeutic exercise program. Hip flexion at symptom onset was assessed longitudinally in a standardized supine position using IMUs [5,6] and a markerless motion capture system [7]. Pain intensity was recorded using the Visual Analog Scale (VAS). Associations between biomechanical and clinical changes were examined using correlation analyses, while agreement between measurement systems was assessed using Bland–Altman analysis.

Results: Hip flexion increased over the rehabilitation period, accompanied by reductions in pain intensity. Strong agreement was observed between markerless and IMU-derived measurements ($r = 0.85$). Bland–Altman analysis demonstrated a small systematic underestimation of hip flexion by the markerless system (bias = −3.44°; limits of agreement: −9.71° to 2.32°). Improvements in hip flexion were moderately associated with reductions in pain for both markerless-derived ($r = −0.54$) and IMU-derived measurements ($r = −0.59$).

Discussion: The findings suggest that improvements in symptom-provoking hip flexion may be associated with reductions in pain during rehabilitation in individuals with CNLBP [8]. Furthermore, the markerless system demonstrated the ability to detect clinically relevant movement changes while showing acceptable agreement with IMU-derived measurements [9]. These findings support the potential clinical utility of both technologies for longitudinal movement assessment in rehabilitation settings [4,9,10].

Limitations: The pilot design, small sample size, absence of a control group, and lack of comparison with a laboratory-based optical motion capture system limit the generalizability of the findings.

Conclusions: This pilot study supports the feasibility of integrating objective motion analysis into CNLBP rehabilitation. Future studies involving larger cohorts, control groups, and laboratory-based reference systems are warranted to further investigate the clinical relevance of hip mobility changes and the applicability of markerless motion capture technologies.

References:

Waddell, G. (2004). The back pain revolution (2nd ed.). Churchill Livingstone.

Kim, S. H., Kwon, O. Y., Yi, C. H., Cynn, H. S., Ha, S. M., & Park, K. N. (2014). Lumbopelvic motion during seated hip flexion in subjects with low-back pain accompanying limited hip flexion. European Spine Journal, 23(1), 142–148. https://doi.org/10.1007/s00586- 013-2973-4

Benfanti, T., Brumitt, J., Matheson, J., & Meira, E. P. (2017). Hip and lumbar spine physical examination findings in people presenting with low back pain, with or without lower extremity pain. Journal of Orthopaedic & Sports Physical Therapy, 47(4), 233–241. https://doi.org/10.2519/jospt.2017.6735

Trinidad-Fernández, M., Cuesta-Vargas, A., Vaes, P., et al. (2021). Human motion capture for movement limitation analysis using an RGB-D camera in spondyloarthritis: A validation study. Medical & Biological Engineering & Computing, 59(10), 2127–2137. https://doi.org/10.1007/s11517-021 02406-x

Tsirmpini, N. M., Foti, E., Triantafyllou, A., Kyriakidou, M., Gkrilias, P., & Papagiannis, G.(2025). Quantitative data to evaluate clinical Pilates efficacy in chronic low back pain using inertial measurement units. Engineering Proceedings, 81(1), 15. https://doi.org/10.3390/engproc2025081015

Triantafyllou, A., Papagiannis, G., Stasi, S., Gkrilias, P., Kyriakidou, M., Kampouroglou, E., Skouras, A.-Z., Tsolakis, C., Georgoudis, G., Savvidou, O., et al. (2023). Lumbar kinematics assessment of patients with chronic low back pain in three bridge tests using miniaturized sensors. Bioengineering, 10(3), 339. https://doi.org/10.3390/bioengineering10030339

Papagiannis, G., Triantafyllou, A., Yiannopoulou, K. G., Georgoudis, G., Kyriakidou, M., Gkrilias, P., Skouras, A. Z., Bega, X., Stasinopoulos, D., Matsopoulos, G., et al. (2024). Hand dexterities assessment in stroke patients based on augmented reality and machine learning through a box and block test. Scientific Reports, 14, 10598. https://doi.org/10.1038/s41598-024-60578-5

Wong, T. K. T., & Lee, R. Y. W. (2004). Effects of low back pain on the relationship between the movements of the lumbar spine and hip. Human Movement Science, 23(1), 21–34. https://doi.org/10.1016/j.humov.2004.03.004

Song, K., Hullfish, T. J., Scattone Silva, R., Silbernagel, K. G., & Baxter, J. R. (2023). Markerless motion capture estimates of lower extremity kinematics and kinetics are comparable to marker-based across eight movements. Journal of Biomechanics, 157, 111751. https://doi.org/10.1016/j.jbiomech.2023.111751

Auer, S., Süß, F., & Dendorfer, S. (2024). Using markerless motion capture and musculoskeletal models: An evaluation of joint kinematics. Technology and Health Care, 32(5), 3433–3442. https://doi.org/10.3233/THC-240202

sciforum-183349: Portable electrochemical immunosensor applied to the fibronectin biomarker determination in epithelial extracellular vesicles samples

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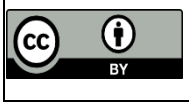
Introduction: In recent years, fibronectin (FN) has emerged as a promising early biomarker for breast cancer (BC) due to its increased expression in tumor microenvironments and its association with cancer progression and metastasis. Detecting FN levels in biological samples offers valuable potential for the early diagnosis and prognosis of BC, improving patient outcomes through timely intervention. We developed and characterized a portable electrochemical immunosensor for FN biomarker quantification in epithelial extracellular vesicles samples (EVs).Methods: In this work, a screen-printed carbon electrode (SPCE) was modified with a mesoporous nanomaterial (CMK-9/KIT-6). Specific monoclonal anti-FN antibodies were immobilized on the silica KIT-6 nanomaterial, so the cancer biomarker was detected using a competitive immunoassay method. Moreover, the carbon CMK-9 nanostructure increases the electroactive surface area, and therefore the sensitivity in the quantification. FN biomarker present in the EVs sample was allowed to compete with FN-horseradish peroxidase (HRP) conjugated for the specific recognizing sites of immobilized anti-FN monoclonal antibodies. After that, the enzyme in the presence of hydrogen peroxide catalyzes the catechol oxidation, whose back electrochemical reduction was detected on the nanostructured electrode at -0.1 V. In this system, the FN concentration in the EVs sample was indirectly proportional to the FN HRP conjugated, showing a higher current by amperometry.Results: The immunosensor demonstrated high selectivity and stability with a linear relationship observed in the 0-100 ng mL^{-1} concentration range. Under optimized conditions, it achieved a detection limit of 6 pg mL^{-1}, significantly lower than that of a commercial ELISA kit (0.1 ng mL^{-1}). The accuracy and reproducibility were validated against ELISA using spiked EVs, yielding intra- and inter-assay coefficients of variation below 4.32% and 6.28%, respectively. Moreover, the correlation between the results obtained with our portable immunosensor and the reference ELISA shows a straight line with a slope of 0.999, indicating good agreement between the two methods.Conclusions: The proposed portable immunosensor provides a highly sensitive, low-cost, and reproducible alternative to traditional benchtop assays. While further clinical validation with patient cohorts is required, this platform represents a promising step toward decentralized point-of-care tools for breast cancer monitoring.



sciforum-177292: Privacy-Preserving Multiparty Computation for Quantum-Resilient Healthcare Sensor Networks: A Systematic Review

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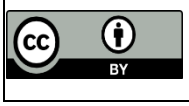
Secure multiparty computation (MPC) enables multiple entities to collaboratively compute functions over private inputs without revealing the underlying data. In modern healthcare systems, distributed sensor and actuator networks—comprising wearable devices, implantable sensors, edge gateways, and clinical cloud platforms—require privacy-preserving collaborative analytics to support diagnosis, monitoring, and automated therapeutic decisions. At the same time, the rapid advancement of quantum computing threatens many classical cryptographic foundations underpinning secure medical data exchange and distributed computation. This systematic literature review (SLR) investigates Post-Quantum and quantum secure multiparty computation protocols ([P]Q-MPC) and evaluates their suitability for deployment in sensor and actuator network environments, particularly in healthcare Internet of Things (IoMT) systems. Twenty primary studies published between 2022 and early 2025 were systematically identified and analyzed. The review categorizes protocols according to cryptographic assumptions, primitives, supported multiparty functionalities, architectural models, threat models, and availability of experimental validation.

The findings reveal a dominant reliance on quantum cryptographic techniques, with widespread use of quantum key distribution and quantum one-time pad encryption. Third-party-assisted architectures are prevalent, reflecting practical deployment models such as edge- or cloud-assisted healthcare networks. Most protocols focus on foundational functionalities—including private set intersection, summation, maximum/minimum computation, and logical operations—which align closely with typical healthcare sensor network requirements such as distributed aggregation, anomaly detection, and secure decision triggering. However, scalability analysis and real-world performance evaluation remain limited. This review identifies research gaps and outlines future directions for designing quantumresilient MPC protocols suitable for large-scale healthcare sensor and actuator systems. The results provide researchers and practitioners with a structured foundation for integrating Post-Quantum and quantum-secure computation into next-generation medical IoT infrastructures.



sciforum-181762: Sensor and Actuator Networks in Occupational Ergonomics: Status, Challenges, and Opportunities for Developing Economies

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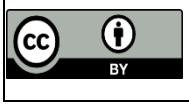
Wearable sensors and Wireless Sensor Networks (WSN) are advancing occupational ergonomics by enabling continuous monitoring of worker health, environmental conditions, and performance indicators. The integration of Internet of Things (IoT) technologies into industrial environments supports real-time data fusion between physiological signals and environmental parameters such as temperature, vibration, and workload intensity to form closed-loop ergonomic systems. However, high dependence on manual labor, limited monitoring infrastructure, and elevated injury risks remain critical challenges in developing economies. This paper presents a thematic review of sensor–actuator networks in occupational ergonomics, focusing on implementation barriers and emerging opportunities in resource-constrained settings. Drawing on documented applications, the review identifies a central gap: existing studies emphasize passive sensing and data acquisition, with limited integration of actuator-based systems that translate environmental and physiological data into real-time corrective or assistive interventions. This limits the development of responsive systems capable of triggering feedback actions such as haptic alerts, adaptive workload redistribution, and environmental adjustments. Integrating low-cost sensor–actuator networks with edge computing and artificial intelligence is therefore discussed as a pathway toward scalable solutions, where local processing enables real-time physical actuation in low-connectivity environments. The paper concludes by outlining future research directions to improve system reliability, affordability, and deployment of responsive sensor–actuator frameworks, contributing a structured perspective for advancing closed-loop ergonomic systems in resource-constrained environments.



Session 5. Big Data, Computing and Artificial Intelligence

sciforum-183642: Heuristic-Based Detection of Anomalous Behavior in Software-Defined Networks

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Introduction:

The continuous evolution of modern communication networks, driven by cloud computing, Internet of Things (IoT), edge computing, and large-scale virtualization, has significantly increased both the complexity of network infrastructures and the volume of generated network data. Software-Defined Networking (SDN) has emerged as a paradigm that separates the control plane from the data plane, enabling centralized management, global visibility, and dynamic programmability. These features support flexible configuration, efficient resource utilization, and large-scale traffic data analysis. However, they also introduce new security challenges, as the SDN controller becomes a critical point of failure and a potential target for attacks. Among the most common threats in SDN environments are traffic flooding, Distributed Denial of Service (DDoS), and port scanning attacks, which can overwhelm network resources and degrade Quality of Service (QoS). Traditional intrusion detection systems often rely on signature-based techniques or computationally intensive machine learning models, which may not be suitable for real-time detection in data-intensive environments due to latency and scalability limitations. Therefore, there is a strong demand for efficient, lightweight, and adaptive detection mechanisms capable of processing large-scale network data streams in real time within SDN infrastructures while maintaining high accuracy.

Methods:

We propose a heuristic-based anomaly detection framework specifically designed for SDN environments, focusing on efficiency, interpretability, and real-time performance. The proposed approach leverages the centralized SDN controller to continuously collect and analyze flow-level statistics from OpenFlow-enabled switches. The extracted features include packet rate, byte count, flow duration, number of packets per flow, average inter-arrival time, source IP entropy, and connection frequency per host. Based on these features, a set of heuristic rules was established to characterize normal network behavior and identify deviations that may indicate malicious activity. For example, a sudden increase in packet rate combined with a high number of short-lived flows originating from a single source is interpreted as a potential flooding attack, while repeated connection attempts to multiple destination ports within a short time interval indicate port scanning behavior. The framework also incorporates adaptive thresholding, where thresholds are dynamically adjusted based on baseline traffic profiles to improve detection robustness under varying network conditions. The proposed solution was implemented using the Mininet network emulator integrated with the Ryu SDN controller, enabling realistic and reproducible experimental scenarios. Multiple network topologies and traffic conditions were simulated, including normal operation and attack scenarios such as SYN flood, UDP flood, and both horizontal and vertical port scans. The detection module operates continuously in real time, periodically evaluating network metrics and applying heuristic rules to classify traffic flows. For reproducibility, flow statistics were collected from the SDN controller at fixed 1-second intervals, and anomaly scores were computed using a sliding analysis window of 10 seconds. Adaptive thresholds were updated every 30 seconds based on recent baseline traffic behavior, using moving averages and standard deviation ranges to distinguish normal variations from suspicious deviations. Upon detecting anomalous behavior, the system automatically triggers mitigation actions by installing high-priority flow rules in the data plane to block or rate-limit suspicious traffic sources, thus minimizing the impact of attacks.

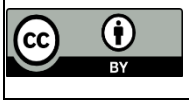
Results:

The proposed framework was evaluated through an extensive set of experiments conducted in a simulated SDN environment consisting of 30 hosts, 8 OpenFlow switches, and a centralized controller. The evaluation considered multiple performance metrics, including detection accuracy,

precision, recall, F1-score, false positive rate, detection latency, throughput impact, and computational overhead. The results demonstrate that the heuristic-based approach achieves a detection accuracy of 96.1% for flooding attacks and 94.2% for port scanning activities. Precision and recall values reached 95.6% and 96.8%, respectively, resulting in an F1-score of 96.2%, indicating high reliability in identifying malicious traffic. The false positive rate remained low, at approximately 3.2%, confirming the model's ability to distinguish legitimate traffic from anomalous patterns. The average detection latency was measured at approximately 82 milliseconds, enabling near real-time detection and response. In terms of system performance, the CPU utilization of the controller increased by only 10–14%, while memory usage showed negligible variation, demonstrating the lightweight nature of the approach. Furthermore, the automated mitigation mechanism reduced malicious traffic volume by up to 91% within the first few seconds after detection, significantly improving network stability and reducing packet loss. Additional experiments under varying traffic loads confirmed the scalability of the proposed method, maintaining consistent performance even when network traffic increased by 150% compared to baseline conditions. Comparative analysis was performed against representative statistical baseline methods, including fixed-threshold detection and moving-average-based anomaly detection. Detection accuracy was adopted as the main comparison metric, while detection latency was used as a secondary performance metric. Compared with these baselines, the proposed heuristic framework improved detection accuracy by approximately 15% and reduced detection time by nearly 40%, highlighting its effectiveness for real-time SDN security monitoring.

Conclusions:

The findings of this study demonstrate that heuristic-based techniques can provide an effective, efficient, and scalable solution for anomaly detection in SDN environments. By exploiting the centralized control and global visibility inherent to SDN, the proposed framework enables fast and accurate identification of malicious traffic patterns without the need for complex training procedures or large datasets. This makes the approach particularly suitable for real-time applications and resource-constrained environments, where rapid response and low overhead are critical. The integration of adaptive thresholding and automated mitigation strategies further enhances the resilience of the network against a wide range of attacks. Although the current implementation focuses on common attack scenarios such as flooding and port scanning, the framework can be extended to detect more sophisticated threats by incorporating hybrid approaches that combine heuristics with machine learning or statistical models. Future work will investigate the deployment of the proposed solution in large-scale and heterogeneous environments, including 5G and edge computing scenarios, as well as its integration with intent-based networking and autonomous security management systems. Overall, this research contributes to the development of practical and high-performance security mechanisms for next-generation programmable networks.



sciforum-181302: A Physics-Informed Graph Reinforcement Learning Framework for Robust Coordinated Control of Sub-Synchronous Oscillations in Weak Grids with Multi-Machine Inverter-Based Resources

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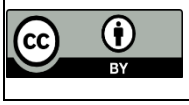
The rise of inverter-based resources and converter-interfaced renewable energy systems has changed the dynamic traits of modern power systems, increasing susceptibility to sub-synchronous oscillations and resonance under weak-grid conditions. These oscillations stem from intricate interactions between converter control loops, network impedance, electromechanical dynamics, and control mechanisms, which can lead to poorly damped modes, instability, and large-scale disturbances. Conventional mitigation methods, such as damping controllers, adaptive filtering, FACTS compensation, and optimization tuning, often face issues like model dependency, fixed parameters, limited operating ranges, and poor coordination among distributed IBRs in uncertain conditions. This paper proposes a Physics-Informed Graph Reinforcement Learning (PI-GRL) framework to adaptively and coordinately mitigate SSOs in multi-machine IBR-dominated weak power systems. The proposed framework is validated on a modified IEEE 39-bus system with synchronous generators, DFIG/PMSG wind farms, and hybrid grid-forming/grid-following converters. High-resolution PMU data, including voltage, current, and power measurements, support data-driven monitoring and control.

The PI-GRL framework combines a Physics-Informed Graph Neural Network (PI-GNN) with multi-agent reinforcement learning (MARL) and a H∞ robust control layer. The PI-GNN incorporates power-flow constraints, swing dynamics, converter control relationships, and network topology into a graph, allowing for precise identification of critical oscillatory modes and overall system stability characteristics. Distributed MARL agents coordinate damping control by adapting converter parameters, virtual impedance settings, and current injection references based on graph features. The framework uses decentralized agent coordination and lightweight inference for real-time deployment with minimal computational load. The H∞ robust control layer adds stability and resilience against parameter uncertainty, measurement noise, and external disturbances. The proposed approach is assessed across various operating scenarios, such as low short-circuit ratio conditions (SCR 2), different series-compensation levels (30–70%), renewable penetration above 70%, random wind-speed and load fluctuations, three-phase faults, post-fault recovery, and mixed grid-forming/grid-following interactions. Performance assessment involves eigenvalue analysis, damping-ratio evaluation, participation-factor analysis, impedance-based stability assessment, and electromagnetic transient simulations.

Simulation results show that the PI-GRL framework greatly improves oscillatory stability, increasing critical-mode damping ratios from about 0.03–0.06 to 0.18–0.32, with average enhancements of 250–400%. Oscillation settling times drop by 55–70%, and peak oscillation amplitudes fall by 60–80% compared to traditional damping-control methods. Comparative studies show that GA/PSO-optimized controllers, battery-energy-storage-based damping methods, adaptive multi-modal damping controllers, and reinforcement-learning-based supplementary damping controllers achieve 30–50% faster oscillation suppression, 25–45% greater damping enhancement, and improved robustness in various operating conditions.

The framework effectively addresses coupled oscillatory mechanisms, such as induction-generator effects, torsional interactions, and converter-control-induced oscillations. The generalization capability is shown across various operating conditions and disturbances not directly faced during training, yet within the range of configurations and scenarios considered during training and validation. The proposed PI-GRL framework offers a scalable and effective solution for coordinated SSO mitigation and stability improvement in renewable-dominated weak-grid settings.



sciforum-165570: Multimodal Explainable Artificial Intelligence (XAI) Applied to Parkinson's and Alzheimer's Diseases

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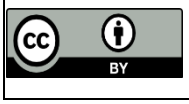
Title: Multimodal Explainable Artificial Intelligence (XAI) Applied to Parkinson's and Alzheimer's Diseases

Abstract: Neurodegenerative disorders, specifically Parkinson's (PD) and Alzheimer's disease (AD), present significant diagnostic challenges due to their heterogeneous symptomatology and overlapping clinical features. While deep learning has demonstrated remarkable potential in automated diagnosis, the "black box" nature of these models hinders their integration into clinical workflows, where interpretability is paramount. This presentation introduces a comprehensive framework for Multimodal Explainable Artificial Intelligence (XAI) tailored to the early detection and progression monitoring of PD and AD. We utilize a [hybrid CNN-Transformer] architecture with a [late fusion] strategy to integrate diverse data modalities. By fusing neuroimaging [(MRI/PET)] and non-invasive biomarkers [(voice or gait analysis)], the proposed approach captures the multifaceted pathology of these diseases more effectively than unimodal systems. The model was evaluated on subsets of the public [ADNI and PPMI] cohorts, comprising approximately [1,200] subjects with paired multi-omic data. Crucially, the framework integrates XAI techniques, including SHAP (SHapley Additive exPlanations) and attention mapping, to elucidate the algorithmic decision-making process. The clinical validity of these explainability outputs was strictly assessed through [expert neuroradiologist review and localization agreement] with established anatomical biomarkers. This allows clinicians to confidently visualize specific anatomical regions or signal features driving the model's predictions. Empirical results demonstrate that our multimodal fusion achieves an AUC of [0.94] and an accuracy of [91%], outperforming standard unimodal baselines by [8-10%]. Ultimately, this work bridges the gap between high-performance AI and clinical trust, paving the way for reliable, personalized computer-aided diagnostic tools in neurology.



sciforum-186393: Topological Data Analysis (TDA)-based Feature Engineering for Reinforcement Learning-based Trading Strategies in Financial Markets

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Motivation

Algorithmic trading systems based on deep reinforcement learning (RL) have proliferated over the past five years, yet the representations consumed by these agents remain dominated by classical technical indicators — moving averages, oscillators, volatility bands — that compress price dynamics into local, largely linear summaries. Such representations are well understood and computationally cheap, but they discard the global geometric organisation of the trajectory: clustering structure, recurrence loops, and higher-dimensional cavities that emerge when a univariate price series is lifted into a reconstructed phase space. Topological data analysis (TDA), and persistent homology in particular, provides a principled, stability-guaranteed framework for extracting precisely these multiscale geometric features. Prior applications of TDA to finance have concentrated on descriptive analyses — early-warning signals before market crashes, persistence-landscape diagnostics across crises — or on supervised forecasting. To our knowledge, no prior study has systematically integrated persistence-based descriptors into the state representation of a reinforcement learning trading agent under a leakage-controlled experimental protocol. This work fills that gap.

Contribution

We present a deep Q-network (DQN) trading agent whose state vector is constructed from descriptors of the persistent homology of recent price dynamics, and we benchmark this agent against twelve alternative state representations spanning the standard taxonomy of technical, statistical, and temporal feature families. The novelty is threefold: (i) the first systematic coupling of persistent-homology descriptors with off-policy deep RL for sequential trading decisions; (ii) a strictly causal embedding construction that precludes look-ahead at the feature-extraction stage; and (iii) a unified experimental protocol that places topological features and conventional indicators under identical agent architecture, hyperparameters, and evaluation criteria, so that observed performance differences are attributable to the representation rather than to modelling choices. Data and task Hourly OHLC data are used for six USDT-quoted cryptocurrencies (BNB, BTC, ETH, XRP, ADA, LTC) covering January 2018 to January 2023, and for four traditional instruments — the CAC 40 equity index, WTI crude oil futures, the EUR/USD exchange rate, and the iShares Core MSCI Europe ETF — covering January 2023 to June 2024. For each segment, training and held-out test windows are defined non-overlappingly: July 2019 – June 2021 (train) and July – December 2021 (test) for cryptocurrencies; January – December 2023 (train) and January – June 2024 (test) for traditional assets. The trading task is formulated as a Markov decision process with a binary action space {long, short}, and the one-step reward is the realised log-return scaled by the agent's current position.

TDA pipeline. Each univariate price series is mapped into a reconstructed phase space via a strictly causal time-delay embedding: at decision time t, the embedded vector $x_t = (p_{t-d\tau}, \ldots, p_{t-\tau})$ uses only observations strictly preceding t, so that the contemporaneous price is never exposed to the agent. The embedding dimension is fixed at $d = 3$ and the delay grid is $\tau \in \{72, 168\}$ hours, corresponding to roughly three days and one week respectively. Sliding windows of length $w \in \{336, 504, 720, 1080\}$ hours (approximately two, three, four-and-a-half, and six weeks) are then applied to the embedded trajectory, generating a family of local point clouds in $\mathbb{R}^3$. For each point cloud, the Vietoris–Rips filtration is constructed and persistent homology is computed up to

dimension two, yielding persistence diagrams in H_0 (connected components), H_1 (loops), and H_2 (voids). Three scalar functionals — persistence entropy, maximum amplitude, and feature count — are extracted per homology dimension, producing nine descriptors per (τ, w) configuration. Concatenation across the 2 × 4 grid yields a 72-dimensional topological state vector, min–max normalised to [0, 1]. RL setup The agent is a DQN with a multilayer perceptron approximator, learning rate 10^{-2}, batch size 128, replay buffer of 10 000 transitions, discount factor $\gamma = 0.99$, target-network synchronisation every 100 updates, and ε-greedy exploration over 10^5 training steps. Off-policy value learning is chosen over policy-gradient alternatives such as PPO or SAC on three grounds: the action space is small and discrete, favouring value-based methods that provide direct per-action estimates; experience replay enables sample-efficient reuse of historical transitions under a fixed data budget; and the smaller hyperparameter footprint allows the contribution of the representation to be isolated from algorithm-specific tuning. Baselines Twelve baseline state representations are evaluated under identical DQN architecture and hyperparameters, spanning trend indicators (simple and exponential moving averages), momentum indicators (MACD, RSI, stochastic oscillator), volatility indicators (Bollinger Bands, average true range), and statistical or temporal feature families (lagged returns, calendar/datetime features, rate-of-change and difference features, STL trend–seasonal decomposition, and time-delay embedding followed by PCA). Each baseline preserves the strictly causal construction of the topological variant, ensuring fair comparison.

Results

The TDA-augmented agent achieves the strongest performance across all four evaluation metrics: mean reward 0.0032 versus 0.0016 for the next-best baseline (TDE-PCA), final net worth 1712 versus 1344, Sharpe ratio 1.39 versus 0.66, and Sortino ratio 2.19 versus 0.97. Wilcoxon signed-rank tests on paired per-asset metric values confirm that the topological agent outperforms every baseline at the 5 % significance level on the majority of metric–comparator pairs, and at the 10 % level on the remainder. Maximum drawdown is comparable across all methods, indicating that the return advantage of the topological representation is not obtained at the cost of additional downside risk. Reproducibility and scope All hyperparameters (embedding dimension, delays, window lengths, DQN configuration, training horizon) are specified, and feature extraction relies on standard open-source persistent-homology libraries. Evaluation is frictionless; the cost-sensitivity analysis is left as an extension. The framework is asset-agnostic, requiring no domain-specific calibration beyond the embedding grid. The pipeline integrates algebraic-topological structure extraction with modern deep RL applied to multi-asset hourly streams, aligning directly with the Big Data, Computing, and AI scope of CSAN.

References

L. A. Leaverton, ‘Analysis of Financial Time Series using TDA: Theoretical and Empirical Results’.

M. Gidea and Y. Katz, ‘Topological Data Analysis of Financial Time Series: Landscapes of Crashes’, Physica A: Statistical Mechanics and its Applications, vol. 491, pp. 820–834, Feb. 2018, doi: 10.1016/j.physa.2017.09.028.

N. Ravishanker and R. Chen, ‘Topological Data Analysis (TDA) for Time Series’. arXiv, Sep. 23, 2019. Accessed: May 26, 2023. [Online]. Available: http://arxiv.org/abs/1909.10604

P. T.-W. Yen and S. A. Cheong, ‘Using Topological Data Analysis (TDA) and Persistent Homology to Analyze the Stock Markets in Singapore and Taiwan’, Front. Phys., vol. 9, p. 572216, Mar. 2021, doi: 10.3389/fphy.2021.572216.

S. W. Akingbade, M. Gidea, M. Manzi, and V. Nateghi, ‘Why Topological Data Analysis Detects Financial Bubbles?’ arXiv, Apr. 13, 2023. Accessed: May 26, 2023. [Online]. Available: http://arxiv.org/abs/2304.06877

sciforum-184375: Uncertainty-Aware Congestion Event Prediction with Interval Neural Network

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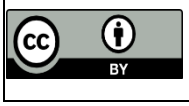
This work investigates uncertainty-aware early prediction of TCP congestion events using sender-side socket telemetry collected under controlled Mininet emulation. Two supervised datasets are constructed for TCP Reno and TCP Cubic from a total of 600 single-bottleneck scenarios (300 per congestion-control algorithm), covering diverse conditions through variations in bandwidth, round-trip time, queue size, and background traffic mixes. Socket snapshots are sampled every 30 ms and include key TCP state variables such as congestion window, RTT, RTO, retransmission counter, pacing rate, slow-start threshold, and derived temporal features. Each sample is labeled as an imminent congestion event when a local maximum of the congestion window is followed by a decrease, targeting the pre-reduction phase preceding congestion manifestation.

We compare a standard point-logit LSTM with an Interval LSTM that produces per-class logit intervals. The proposed model generates 12 latent criteria logits per class and aggregates them via min/max operators to form interval bounds. Classification relies on midpoint logits, while interval widths are trained using an auxiliary calibration objective derived from midpoint probabilities, combined with a width regularization term to prevent degenerate solutions. This design enables the model to provide both predictions and a sample-wise reliability indicator.

Experiments are conducted using stratified 70/15/15 train/validation/test splits, median imputation, feature standardization, class-weighted cross-entropy, and early stopping. On the Reno dataset, the standard LSTM achieves 0.877 accuracy and 0.863 macro-F1, while the Interval LSTM achieves 0.879 accuracy and 0.864 macro-F1. On the Cubic dataset, the standard LSTM obtains 0.908 accuracy and 0.888 macro-F1, compared to 0.907 accuracy and 0.888 macro-F1 for the Interval model. Reliability analysis shows that interval width correlates positively with prediction error, with predicted-class width–error correlations of approximately 0.660 for Reno and 0.712 for Cubic. Probability RMSE values are 0.281 (Reno) and 0.246 (Cubic), confirming meaningful alignment between interval width and predictive uncertainty.

These results demonstrate that interval-valued logits provide a practical reliability signal without degrading classification performance. In a congestion-control context, predicted probabilities can trigger proactive responses, while interval width can inform the confidence of such actions, enabling more conservative behavior under uncertainty and improving robustness to variable network conditions.



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