ICINCO 2026

23rd International Conference on Informatics in Control, Automation and Robotics

PROCEEDINGS

Volume 1

Angers, France

26 - 28 October, 2026

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ICINCO 2026

Proceedings of the
23rd International Conference on
Informatics in Control, Automation and Robotics

Volume 1

Angers - France

October 26 - 28, 2026

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Edited by Giuseppina Gini, Antonella Ferrara and Dimitar Filev

Printed in Portugal
ISSN: 2184-2809
ISBN: 978-989-758-870-9
DOI: 10.5220/0000224600004979
Depósito Legal: 570354/26

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BRIEF CONTENTS

INVITED SPEAKERS IV

SPECIAL SESSIONS CHAIRS IV

ORGANIZING COMMITTEES V

PROGRAM COMMITTEE VI

AUXILIARY REVIEWERS IX

SPECIAL SESSIONS PROGRAM COMMITTEE IX

SELECTED PAPERS BOOK X

FOREWORD XI

CONTENTS XIII

INVITED SPEAKERS

Johan Suykens
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Bogdan Epureanu
University of Michigan
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Maria Domenica Di Benedetto
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SPECIAL SESSION ON BRIDGING THE GAP IN COLLABORATIVE ROBOTICS: FROM THEORY TO REAL APPLICATIONS

Juan Corrales Ramón, Universidade de Santiago de Compostela, Spain

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SPECIAL SESSION ON HYBRID INTELLIGENCE: INTEGRATING PHYSICS-BASED PRINCIPLES WITH DATA-DRIVEN AI

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SELECTED PAPERS BOOK

A number of selected papers presented at ICINCO 2026 will be published by Springer in a LNEE Series book. This selection will be done by the Conference Chair and Program Co-chairs, among the papers actually presented at the conference, based on a rigorous review by the ICINCO 2026 Program Committee members.

FOREWORD

This book contains the proceedings of the 23rd International Conference on Informatics in Control, Automation and Robotics. This year, ICINCO is held in collaboration with the ESEO, which hosts this event in Angers, France, on October 26-28, 2026. It was sponsored by the Institute for Systems and Technologies of Information, Control and Communication (INSTICC) and technically co-sponsored by the IEEE SMC - TC on Evolving Intelligent Systems and the International Federation of Automatic Control. ICINCO 2026 was also organized in cooperation with the ACM Special Interest Group on Artificial Intelligence, the Association for the Advancement of Artificial Intelligence and the International Neural Network Society.

The purpose of the International Conference on Informatics in Control, Automation and Robotics (ICINCO) is to bring together researchers, engineers and practitioners interested in the application of informatics to Control, Automation and Robotics, covering topics related to Intelligent Control Systems, Optimization, Robotics, Automation, Signal Processing, Sensors, Systems Modelling and Control, and Industrial Informatics.

ICINCO 2026 received 154 paper submissions from 40 countries, of which 25% were accepted and published as full papers. A double-blind paper review was performed for each submission by at least 2, but usually 3 or more, members of the International Program Committee, which is composed of established researchers and domain experts.

The high quality of the ICINCO 2026 program is enhanced by the keynote lectures delivered by distinguished speakers who are renowned experts in their fields: Johan Suykens (KU Leuven, Belgium), Maria Domenica Di Benedetto (University of L'Aquila, Italy) and Bogdan Epureanu (University of Michigan, United States).

The conference is complemented by a Special Session on Hybrid Intelligence: Integrating Physics-Based Principles with Data-Driven AI, chaired by Ndivhuwo Makondo, Vittorio Lippi and Leonard Johard, and a Special Session on Bridging the Gap in COllaborative roBOtics: from Theory to real Applications, chaired by Pedro Dinis Gaspar, Chedli Bouzgarrou, Daniel Sánchez and Juan Antonio Corrales Ramón. Furthermore, a Tutorial on Designing an Industrial Robot within the ROS2 Environment, Forward Kinematics, Inverse Kinematics, and Motion Planning was offered.

All presented papers will be available at the SCITEPRESS Digital Library and will be submitted for evaluation for indexing by SCOPUS, Google Scholar, DBLP Computer Science Bibliography, Semantic Scholar, Engineering Index and Web of Science / Conference Proceedings Citation Index.

Several awards, based on the combined marks of paper reviewing, as assessed by the Program Committee, and the quality of the presentation, as assessed by session chairs at the conference venue, are conferred at the conference's closing session as recognition for the best contributions.

Authors of selected papers will be invited to submit extended versions for inclusion in a forthcoming book of ICINCO Selected Papers to be published by Springer, as part of the LNEE Series. Some papers will also be selected for publication of extended and revised versions in the special issue of the Springer Nature Computer Science Journal.

The program for this conference required the dedicated effort of many people. Firstly, we must thank the authors, whose research efforts are reported here. Next, we thank the members of the Program Committee and the auxiliary reviewers for their diligent and professional reviewing. We would also like to deeply thank the invited speakers for their invaluable contribution and for taking the time to prepare their talks. Finally, a word of appreciation for the hard work of the INSTICC team; organizing a conference of this level is a task that can only be achieved by the collaborative effort of a dedicated and highly competent team.

We wish you all an exciting and inspiring conference. We hope to have contributed to the development of our research community, and we look forward to having additional research results presented at the next edition of ICINCO, details of which are available at https://icinco.scitevents.org.

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CONTENTS

INVITED SPEAKERS

KEYNOTE SPEAKERS

From Shallow to Deep Kernel Machines 5
Johan Suykens

Human Autonomy Teaming Strategies for Physical Orchestrated Intelligence 7
Bogdan Epureanu

Observability and Diagnosability of Hybrid Dynamical Systems: Theory and Applications 9
Maria Domenica Di Benedetto

INTELLIGENT CONTROL SYSTEMS AND OPTIMIZATION

FULL PAPERS

Learning Changes the World and Then What Was Learned Has Changed: Training and Deploying Neural Networks in the Control Loop 15
Vittorio Lippi

Planning Mobile Project Resources as Integrated Systems: A Research Roadmap for the Assignment, Scheduling, and Routing Problem 27
Ayman R. Mohammed, Majed Hadid and Roberto Baldacci

Adaptive Stochastic Model Predictive Control for Grid-Connected Hybrid Energy Storage Management 39
Taranjitsingh Singh, Boulaid Boulkroune, Maxime Monsieur and Chris Ganseman

An Explainable Neuro-Fuzzy Adaptive Graph KAN–TCN Framework for Short-Term Urban Parking Occupancy Forecasting 51
Mohammad Reza Mohebbi, Farzaneh Keighobadi and Mario Döller

An Evaluation of Deep Learning Models for DBH Estimation Using UAV-LiDAR Data in Eucalyptus Inventory 63
Felipe M. Salles, Adimara B. Colturato, Cristiano R. Reis, Luis Pelin, Marcos G. Quiles and Kalinka Castelo Branco

A Symmetry-Reduced Optimal Control Formulation for Quadrotor Dynamics Based on Noether's Theorem 74
Tanzeela Tasneem, Enzo Avelino, George Kamel, Joseph Chazbani and Daniela Nikolova

Q-Learning in Action: Explainable and Verified Renewable Energy Source Selection 84
Afef Gafsi and Imen Ben Hafaiedh

Combining Large Language Models with Symbolic Reasoning for Robust Aspect-Based Sentiment Analysis 96
Moemen Said, Nadia Smairi, Houda Abadlia and Olfa Belkahla Driss

SHORT PAPERS

MIMO and Multi-Group Comparison Problem in Process Control: A Multivariate Statistical Framework for Systems Represented with Frequency Response Functions 109
Vittorio Lippi, Leonard Johard and Gabriele Landucci

A Biped Walking Consisting of Single-Support and Double-Support Phases 117
Yannick Aoustin and Alexander Formal'Skii

Analysis of Adhesion Effect on Grasp Stability with Robotic Gripper 125
Caroline Pascal and Mathieu Grossard

Robust Bell-State Preparation and Observation in Two-Qubit Systems Using Sliding Mode Methods 133
Kaydian Quintero, Bereket Berhane and Sergey V. Drakunov

Design of Neurocontrollers for Nonlinear Dynamic Systems with Summation and Difference Neurons 141
Ivan Sekaj, Aleš Melichar, Danil Zlobin, Miroslav Halás, Jaromír Skirkanič and Ivan Kenický

An Epipolar Geometry-Based Approach for Distributed Formation Control Using Vision 149
Patricia M. Tavares, Edgar I. Chavez-Aparicio, Jean-Bernard Hayet and Hector M. Becerra

Integrated Multi-Objective Optimization for AMR Fleet Operations in Automotive Manufacturing 157
Ahmed Tolba

STRIDE: Investigating Efficient Sampling Strategies for Neural Approximations of Optimal Control 166
Andrea Giusti, Maxime Monsieur and Branimir Mrak

Runway-Referenced Deep Reinforcement Learning Control for Autonomous Landing of a 6-DoF Aircraft Model 174
Melisa Nisa Aşlayan Üzer and Barış Başpınar

Evolutionary Fixed-Structure H_∞ Controller Synthesis with Performance Robustness against IQCs 182
Philippe Feyel

Spiking Neural Networks for Object Detection: A Review of 2024/2025 Advancements 191
Mikołaj Waśniewski, Jakub Caputa, Wojciech Chmiel and Maciej Wielgosz

A Genetic Algorithm Approach for LPG Transportation Scheduling under Loading and Unloading Constraints 199
Yadira Bravo, Pablo Proaño, Danilo Chavez and Alan Cuenca-Sánchez

Smooth Optimal Tracking-Control Approximating Maximum Control Energy Usage for a Class of Linear Systems with a Nonlinear Output Function and Control Limitations 207
Mir Mamunuzzaman and Jörg Mareczek

Reinforcement Learning Based Distributed Tracking Control of Multiple Uncertain Linear Systems 215
S. Hernandez and Wenjie Dong

Feature-Level Explainability for Hyperdimensional Computing-Based Anomaly Detection 222
Víctor Ortega, Soledad Escolar, Fernando Rincón, Jesús Barba, Julián Caba and Juan Carlos López

ROBOTICS AND AUTOMATION

FULL PAPERS

Model-Free Dynamic Compensation Based on Ultra-Local Modeling for Trajectory Tracking of an Aerial Manipulator 235
Gabriela M. Andaluz, Paulo Leica, Oscar Camacho and Angélica Quito

Enhanced Indoor and Parking Navigation for UGV: A Multi-Layered Algorithmic Overlay for Patchwork++ 243
Kevin Helvig, Julien Marzat and Martial Sanfourche

Visual Servoing under Scalar Depth Uncertainty: Classical, Predictive, and Takagi–Sugeno Control
Boucherika Mohamed Abdelmalek, Jason Chevrie, Laurent Vermeiren, Benyamine Allouche and Antoine Dequidt 252

A Dual-Stream Transformer Architecture for Illumination-Invariant TIR-LiDAR Person Tracking 262
Yuki Minase, Kanji Tanaka, Changjun Wang and Tomoe Hiroki

Model-Based Switching Manifold Embedded Terminal Second-Order Sliding Mode Control for Rehabilitation Exoskeletons 270
Brahim Brahmi, Wissem Dilmi, Jawhar Ghommam and Mohammad H. Rahman

Practical Feature-Based 3D Object Recognition for Complex-Shaped Sand Cores in Casting 278
Cong Huy Nguyen and Yoshiyuki Noda

LoRa-Based Large-Scale Indoor Localization Using Probabilistic Models of Strongest Received Signals 288
J. Ranz-Abad, S. Maldonado-Bascón, S. Lafuente-Arrroyo and R. Flor-Rabadan

Design and Experimental Validation of a 3-DOF Delta Robot with Trajectory Tracking Control
Pablo Rivadeneira, Viviana Moya, Juan Pablo Vásconez, Luis A. Córdova-Tandazo, Angélica Quito and William Chamorro 298

Comparative Evaluation of Path Planning Algorithms and Control Strategies for Omnidirectional Mobile Robot Navigation 308
Mateo García, Viviana Moya, Andrea Pilco, Juan Pablo Vásconez, Álvaro Prado-Romo and William Chamorro

Comparative Analysis of Bio-Inspired Optimization Algorithms for Nonlinear PID Tuning of a Mobile Manipulator 319
Pablo Proaño, Paulo Leica, Gabriela M. Andaluz, William Chamorro and Luis Morales

Continuous-Time Set-Transformers for Asynchronous WiFi-IMU Indoor Localization 331
Mohamed Bachar, Ilyass Abouelaziz and Yuehua Ding

Data-Efficient Pedestrian Multi-Object Tracking via Zero-Shot Detection and Lightweight DINOv3 Re-Identification 343
Manu Gupta, Oliver Zeilerbauer, Mohammad Reza Mohebbi and Mario Doeller

Safe Trajectory Planning and Control via Flatness-Based MPC with Convex Polytopic Constraints
Solal Wargon, Harendra Rangaradjou, Christophe Louembet, Martin Mujica, Adrien Durand-Petiteville and Viviane Cadenat 355

Indoor SLAM and Waypoint Navigation for a Low-Cost Mobile Robot: A Heterogeneous FPGA and Embedded GPU Architecture with BLE-Assisted Localization 365
Tudor Mihai Crihălmeanu, Mircea Paul Mureşan and Sergiu Nedevschi

SHORT PAPERS

A Novel Piecewise Autonomous Multi-Model Odometry Approach 377
Andrea Righetti, Giuseppe Spampinato, Arcangelo Bruna and Giorgio Battistelli

Liquids Detection Using SWIR Data and Deep Learning 383
Antonio Buemi, Andrea Accettola, Arcangelo Ranieri Bruna, Cosimo Ieracitano, Nadia Mammone, Massimo Merenda and Valeria Tomaselli

Deep Global Point Cloud Registration for Long-Term Robot Localization 390
Míriam Máximo, Enrique Heredia-Aguado, Esther González-Amorós, Francisco José Martínez-Peral, Luis Payá, David Valiente and Mónica Ballesta

A Deep Learning Framework for Underwater Perception and Navigation Using Super-Resolution Enhanced YOLOv8 and Reinforcement Learning 398
Khaled Benkhoud, Saliha Sebbane and Sarra Bouzayane

Traversability-Aware Frontier Selection for Goal-Directed Exploration: An Ablation Study 406
Carlos Tampier Cotoras, Frank Höller and Dirk Schulz

Workspace Computation via Constrained Forward Kinematics: Application to Robotic Manipulators 414
Francisco José Martínez-Peral, Míriam Máximo, Mónica Ballesta, José Vicente Segura-Heras, Arturo Gil and Carlos Perez-Vidal

Influence of FEA Modeling Parameters on the Accuracy of Robot-Link Compliance Identification 422
David Eskoundos, Anatol Pashkevich, Kevin Subrin and Stéphane Caro

A Certification-Based Predefined Time for Dynamic Average Consensus for Multi-Agent Systems 430
Muzammil Ali, Muhammad Sabih, Khubaib Ahmad and Aamer Iqbal Bhatti

Automatic Labeling for Low-Light Pedestrian Detection 438
Dimitrios Bouzoulas, Eerik Alamikkotervo and Risto Ojala

KGAT-RL: Kernelized Graph Attention Networks with Drift-Triggered PPO Residual Correction for Robust Multi-Horizon Traffic Forecasting 447
Mohammad Reza Mohebbi, Mohammad Javad Hassanzada, Erfan Ranjbar, Mohammad Soltanirad and Mario Döller

A Bounded Circle Covering Strategy for Mobile Robotics Inspired by Nesting Optimization 455
Stépane Binon, Lucas Si Larbi and Eric Lucet

Redundant Safety Mechanisms of Artificial Intelligence Models for Autonomous Driving 463
Florence Wagner, Heinrich Litagin and Rolf Jung

Multi-Arm Motion Planning Based on Conflict Elimination 471
Matouš Kulhan and Pavel Surynek

Liquid Recurrent Reinforcement Learning for Constrained Multi-UAV 3D Coverage Path Planning 479
Mohammad Reza Mohebbi, Mario Döller and Nauman Ahmed

Robust Fractional-Order Sliding Mode Control for Trajectory Tracking of a Mobile Manipulator 487
Gabriela M. Andaluz, Paulo Leica, Luis Morales, Pablo Proaño and Oscar Camacho

Hamiltonian-Based Human Intention Estimation for Compliant Exoskeleton Robot 495
Brahim Brahmi, Abderraouf Maoudj, Jawhar Ghommam and Mohammad H. Rahman

A Pose-Based AI Coach for Exercise Recognition and Quality Assessment 503
Ahmed Aly, Al Amir Eldomiatty, Zeyad Elsayed and Walid Gomaa

From Reactive to Map-Based AI: Tuned Local LLMs for Semantic Zone Inference in Object-Goal Navigation 511
Yudai Noda, Kanji Tanaka, Sosi Tanaka, Changjun Wang and Tomoe Hiroki

Self-Supervised Appearance-Based in-Plane Rotation Estimation 519
Sreejani Chatterjee, Nichols Taylor and Daniel Nikovski

Vision-Based Excavator Boom Pose Estimation with Sensor-Fused Uncertainty-Aware Tracking 527
Robin Vetsch, Lucas Falch, Christoph Würsch and Sebastien Gros

Optimization of a Higher Order Sliding Mode Controller for Tactical Missile Guidance Applications 538
Mirza Hodžić, Naser Prljača and Jakub Osmić

A Retrofit State Monitoring Framework for Safe Robot-Instrument Interaction in Legacy Analytical Laboratories 547
Mohamed Ali Tlili, Thomas Roddelkopf, Heidi Fleischer and Kerstin Thurow

Monitoring Endangered Animals Using Blockchain and Artificial Vision 555
Ludwin Lope Cala and Roseli Aparecida Francelin Romero

Robotic Manipulator Motion Planning and Obstacle Avoidance Using Physics-Informed Reinforcement Learning via Artificial Potential Fields 563
Edmond Samia, Alexandre Parant, Laurent Arcese and Yuehua Ding

GARL: Grasp-Aware Reinforcement Learning for Robust and Dexterous in-Hand Rotation 571
Guillaume Thomas, Jaonary Rabarisoa, David Filliat, Quoc-Cuong Pham and Mathieu Grossard

Optimization-Based Inverse Kinematics for a 4-DOF Robotic Arm: A Comparative Analysis with Real-Time ROS Implementation 582
Jofre Suárez, Viviana Moya, Juan Pablo Vásconez, Álvaro Prado-Romo, Andrea Pilco and William Chamorro

Towards Single-Contact-Point Textile Unfolding with Hierarchical Point Selection and Trajectory Generation 590
Santiago T. Puente and Carlos Mateo-Agulló

Scene Description Generation for Traffic Scenes Using Segmentation and Visual Language Models 598
Boitor Diana, Sergiu Nedevschi and Raluca Didona Brehar

Fault-Tolerant Multi-Sensor Fusion via Factor Graph Optimisation for Mobile Robot Localisation 606
Clovis Adeler, Maan El Badaoui El Najjar, Cindy Cappelle and Denis Pomorski

TASC: Fast Skill Chaining for Complex Sequential Robotic Tasks via Pure Imitation Learning 614
Ryan James Hayward and Kasim Terzić

Electro-Mechanical Modelling of Generatively Designed Robotic Arm Segments with Integrated Wire Routing 622
Johannes Lamm and Thomas M. Wendt

Mapless Rover Navigation Leveraging Obstacle Perception with k-NN Vector-Space Clustering 629
Giovanni De Gasperis, Sante Dino Facchini and Luigi Iaconi

Testing Video Anomaly Detection through State Space Models on Challenging Real-World Surveillance Datasets 639
Esther González-Amorós, Alberto Chueco, Míriam Máximo, Carlos Viegas, Adrián Peidró and Luis Paya

Comparative Analysis of Eye-in-Hand and Eye-to-Hand Motion Estimation Techniques for Dynamic Target Tracking in Visual Servoing 649
Mario Talarico, Ibrahim Ben-Othman, Andrea Monguzzi, Navvab Kashiri, Andrea Maria Zanchettin, Elena De Momi and Paolo Rocco

Point Cloud Streaming from Mobile Robots under Bandwidth and Scene Complexity Constraints 657
Mohamad El Dika, Jalal Possik, Petra Bilane, Jad Nassar, Roger Achkar and Charles Yaacoub

Tether-Length-Constrained Reference Governance for Cooperative UGV-UAV Agricultural Inspection 664
Ammar Selim, Zhengjia Xu, Mohsen Zahmatkesh and James E. Pickering

Energy-Aware Adaptive Communication for Efficient Mobile Robots 675
Giorgio Vivoli and Navvab Kashiri

Proposal of an Intuitive Robot-Summoning Method for Agricultural Mobile Robots Using a Retroreflective Handheld Device 683
Atsuhiro Ohno, Sho Yokota and Akihiro Matsumoto

AIVFusion+3D Features: An Approach for Features Extraction Aiming to Implement Sensors Data Fusion from Monocular Camera and LIDAR 691
Fernando S. Osorio, Felipe Freitas Maia, Alexandre M. Ishi Jr, Marcos Vinicius da Rocha, Vitor Augusto Pereira and Leticia de Carvalho Pereira

A Real-Time Framework for Multi-Person Reciprocal Line-of-Sight Modeling and Recovery in Human-Robot Interaction 699
Jesus Eduardo Hermosilla-Diaz, Jeeangh Jennessi Reyes-Montiel, Yaser Aguas-Garcia and Antonio Marin-Hernandez

Implementation of an Autonomous Liquid Pouring System Based on Source Container Modeling for Different Target Containers 707
Jeeangh Jennessi Reyes-Montiel, Jesus Eduardo Hermosilla-Diaz, Yaser Aguas-Garcia, Yahir Hernandez-Mella and Antonio Marin-Hernandez

Kalman Filter Fusion of Forward Kinematics and Vision for Robot Pose Estimation in Construction Environments 714
Juan Pablo Cahueque Perez, Christine Chevallereau, Corentin Monet, Loïc Buatois and Andrea Cherubini

SIGNAL PROCESSING, SENSORS, SYSTEMS MODELLING AND CONTROL

FULL PAPERS

Extended Neural Ordinary Differential Equations 727
Leonard Johard and Vittorio Lippi

Robotic Sorting of Dirty Laundry Using a Multispectral Vision-Based Grasping Strategy 736
Ferréol Gagey, Gabriel Prudhomme and Mathieu Grossard

Sliding Mode Control of Single-Mode Photon by Nonlinear Quadrature Actuation 744
Sergey V. Drakunov and Bereket Berhane

A Biquaternion-Based State Observer and Its Application to a Two-Level Quantum System 751
Andrei A. Markov and Sergey V. Drakunov

Beyond Human Captions: Semantic Supervision and PCA-Regularized Decoding for Stable-Diffusion-Based fMRI Reconstruction 760
Abdallah Mohammed AboHassan, Ehab Elshazly, Tetsuji Ogawa and Ahmed Fares

Negative Binomial Mixtures with Data-Driven Initialization for Streaming Overdispersed Count Data 772
Hana Sedláčková and Evženie Uglickich

EJUST-GYM-3: A Multi-View Exercise Dataset for Human Activity Recognition and Motion Analysis 783
Mohamed Abouelella, Ahmed Ashraf and Walid Gomaa

Effects of Seasonality in Dengue Spread Equilibria and Transient Behaviors 795
Flavia Altamura, Paolo Di Giamberardino and Daniela Iacoviello

Implicit Predecessor-Based Region of Attraction Estimation and Robust Invariance Analysis for a Two-Wheeled Inverted Pendulum 805
Lorenzo Fici and Guillaume Ducard

Data-Driven Modeling of Complex MIMO LPV Dynamics: A Scalable Iterative Approach Using Khatri–Rao Matrix Augmentation and Kalman-Enhanced State Estimation 813
Jorge Puerto, Edwar Jacinto and Fredy Martínez

SHORT PAPER

Interpretable Human Activity Recognition via Phase-Space Trajectories 827
Walid Gomaa and Ahmed Gomaa

SPECIAL SESSION ON HYBRID INTELLIGENCE: INTEGRATING PHYSICS-BASED PRINCIPLES WITH DATA-DRIVEN AI

FULL PAPERS

Markerless Human Body Volume and Center of Mass Estimation from Dual RGB-D Cameras with Biomechanical Preliminary Assessment 839
Usman Asghar, Shengjie He, Giulia Bassani, Josep Rueda Collell, Carlo Alberto Avizzano and Alessandro Filippeschi

A Gated Temporal Causality Scheme for Physics-Informed Neural Networks 850
Peng Shu Ng, Elisa Y. M. Ang, Peng Cheng Wang and Teng Yong Ng

When Does Physics Help? A Persistence-Aware Benchmark of Hybrid pH Prediction in Geothermal Steam Washing 857
Massimo Satler and Carlo Alberto Avizzano

SHORT PAPERS

Hybrid Intelligence for Industrial Process Optimization 869
Vittorio Lippi and Leonard Johard

A Simple Gripper Interface for Simulator-Agnostic Cloth Manipulation 877
Abhilash Nayak, Franco Coltraro, Maria Alberich-Carramiñana and Carme Torras

Experimental Comparison of Linear MPC and Adaptive MPC for Transparency in a 1-DOF Elbow Exoskeleton: A Discussion 885
Josep Rueda Collell, Alberto Maria Nobili, Shengjie He, Usman Asghar, Fabio Salsedo and Alessandro Filippeschi

SPECIAL SESSION ON BRIDGING THE GAP IN COLLABORATIVE ROBOTICS: FROM THEORY TO REAL APPLICATIONS

FULL PAPERS

Cobot-Based Operator Assistance for Manual Meat Processing: Experimental Validation on Porcine Cuts 897
Alexis Babut, Chedli Bouzgarrou, Laurent Sabourin and Nicolas Bouton

Facial Emotion Recognition Based on FAUs and DINOv3 Embeddings with Reliability-Gated Fusion 906
Giuseppe Lorenzo Di Prima, Francesco Termine, Ankit Kumar, Giuseppe Sutera, Filippo Sanfilippo and Mario Collotta

Keeping the Franka Emika Panda Alive: A ROS 2 Stack with a Reliable Position Interface 918
Antonio Langella, Davide Risi, Vincenzo Petrone, Enrico Ferrentino and Pasquale Chiacchio

Robust Learning from Demonstration Pipeline Based on Inertial Motion Capture and Force-Synchronised Demonstration Capture for Industrial Demoulding Tasks by Collaborative Robots 930
Alejandro Solar Iglesias, Gabriel Novas Domínguez, Saltanat Seitzhan and Juan Antonio Corrales Ramón

SHORT PAPERS

Automated IMU-Based Ergonomic Evaluation and Postural Risk Assessment for Industrial Automation Frameworks 943
Jorge Galindo, Alejandro Solar, Juan Antonio Corrales Ramón and Hernan Abaunza

Transformer-Based Ego-Motion Filtering for Tracking in Eye-in-Hand Event-Driven Visual Servoing 949
Gabriel Barrigón-Gómez, Adrián Fernández-Casas, Carlos Mateo-Agulló, Juan Antonio Corrales Ramón and Cédric Demonceaux

Slice More, Push Less: Admittance-Controlled Force Amplification for Collaborative Meat Cutting 957
Saltanat Seitzhan and Juan Antonio Corrales Ramon

Design of a Low-Cost Planar Delta Robot for Agri-Food Sorting Applications 964
Simão Lopes, Martim Aguiar, Yebo Lu and Pedro Dinis Gaspar

AUTHOR INDEX 973

Deep Global Point Cloud Registration for Long-Term Robot Localization

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Keywords: 3D Deep Learning, Feature Descriptor, Fine Localization, Light Detection and Ranging, Point Cloud, Pose Estimation.

Abstract: Accurate localization and orientation are fundamental prerequisites for the autonomous navigation of mobile robots and vehicles. To this end, this paper evaluates a method capable of estimating a robot's pose with six degrees of freedom (6DoF) by comparing a real time LiDAR scan with a previously acquired scan of the same environment. Our approach relies on establishing local feature correspondences between the respective point clouds. These local features are extracted via a deep learning architecture originally trained to generate a global descriptor for the entire scan. This study analyses the performance of the model's intermediate layers when repurposed for this task. The analysis is conducted using standard state of the art datasets, supplemented by a proprietary collection of captured scans.

1 INTRODUCTION

The capacity of a mobile robot to navigate autonomously relies on precise knowledge of its position and orientation within the environment. Obtaining an accurate estimation of the 6DoF (Degrees of Freedom) pose is essential for its operation.

To determine this pose in large scale maps, navigation systems employ a hierarchical strategy. First, a coarse pose estimation is obtained, allowing the system to identify the approximate region in which the robot is located by comparing current observations with a previously acquired map (Zhang et al., 2024a).

However, this global estimation lacks metric precision, therefore, it is necessary to apply a local localization method (Zhou et al., 2016) (Garcia and Eskandarian, 2025). These methods achieve exact alignment between currently captured data and the local map. Such methods must be robust to potential changes between the map and the current observation. Consequently, selecting the appropriate sensor is vital. Unlike camera based methods (Alfaro et al., 2026), which are sensitive to fluctuating illumination conditions, 3D LiDAR sensors have become established as the optimal choice for this task (Vilella-Cantos et al., 2026) (Luo et al., 2025), providing direct 3D geometric measurements of the environment.

In this study, we focus on local localization, aiming to obtain the precise position and orientation of the robot from a query scan and a candidate scan from the map, both captured with a 3D LiDAR sensor. To align them, we employ the intermediate layers of the MinkUNeXt network (Cabrera et al., 2025), which provide a semantic descriptor for each point and allow local correspondences to be established between both point clouds. These correspondences are then processed by the RANSAC (Random Sample Consensus) algorithm to compute the exact alignment.

MinkUNeXt was selected as the state of the art in LiDAR-based Place Recognition, with a U-Net topology providing efficient multi-scale representations. Since the network already performs coarse Place Recognition, the same forward pass yields the local features for fine pose estimation, avoiding a second network. Our goal is not to outperform dedicated registration networks, but to determine whether representations learned for Place Recognition already encode sufficient geometric information for registration.

The main contributions of this paper are summarized as follows:

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Máximo, M., Heredia-Aguado, E., González-Amorós, E., Martínez-Peral, F. J., Payá, L., Valiente, D. and Ballesta, M.
Deep Global Point Cloud Registration for Long-Term Robot Localization.
Paper published under CC license (CC BY-NC-ND 4.0)
In *Proceedings of the 23rd International Conference on Informatics in Control, Automation and Robotics (ICINCO 2026) - Volume 1*, pages 390-397
ISBN: 978-989-758-870-9; ISSN: 2184-2809
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- We demonstrate that the intermediate representations of a network trained exclusively for Place Recognition can be reused, without any retraining or fine-tuning, as local feature descriptors for 6DoF point cloud registration.
- We provide a systematic layer-by-layer analysis of a sparse U-Net architecture for this task, identifying the range of layers that offers the optimal trade-off between semantic context and spatial resolution.
- We validate the approach under long-term conditions, with map and query scans captured months apart, across indoor and outdoor environments and two different sensor setups.

The remainder of the paper is organized as follows. Section 2 outlines related research, Section 3 describes the proposed methodology and Section 4 details the experimental framework, including datasets and metrics. Section 5 discusses the results, and Section 6 summarizes the main contributions.

2 RELATED WORK

Point cloud registration is the process of estimating the rigid transformation matrix that aligns two or more 3D point clouds, thereby mapping them into a common coordinate system. The existing literature presents a wide range of methodologies that address this challenge using diverse computational techniques (Zhang et al., 2024b).

Traditional approaches rely on the Iterative Closest Point (ICP) algorithm (Besl and McKay, 1992) and its variants, such as Point-to-Plane ICP (Chen and Medioni, 1992) and GICP (Segal et al., 2009), which iteratively minimize point-to-point or point-to-surface distances. Despite successive improvements in convergence and robustness, these methods share a critical limitation: they require an accurate initial alignment and are prone to converging to local minima otherwise, which makes them unsuitable for scenarios with large initial pose discrepancies such as ours.

Alternative approaches employ deep learning architectures for this purpose. These methods typically extract geometric features from the point clouds to establish correspondences between distinct scans, which are subsequently utilized to estimate the transformation matrix. For instance, Fully Convolutional Geometric Features (FCGF) (Choy et al., 2019) achieves this through the use of 3D sparse convolutions. The primary objective of that work is to estimate LiDAR odometry between consecutive scans separated by at least 10 meters, demonstrating highly robust performance in this task.

To reduce the computational cost of raw 3D processing, frameworks such as OREOS (Schaupp et al., 2019) project LiDAR scans into a 2D representation and extract learned descriptors for retrieval and yaw estimation, which subsequently initialize a refined pose estimation pipeline.

Unlike registration methods such as FCGF, which train a dedicated network to produce local features, our approach requires no task-specific training: we investigate whether representations learned for Place Recognition already encode sufficient geometric information for registration. It also differs from SLAM, which builds the map during operation, since we localize against a previously acquired map with scans separated by months.

3 METHODOLOGY

This section provides an explanation of the methodology employed for fine localization. The process begins with a query LiDAR scan and a previously acquired LiDAR scan from the map, captured at a specific distance and orientation relative to the query. Point descriptors are extracted for each scan to facilitate the establishment of feature correspondences. These correspondences are then utilized to compute the transformation matrix that aligns the two scans (query and map), thereby enabling the determination of the current position and orientation of the query. The scheme of the method is represented in Figure 1.

3.1 Local Feature Extraction

Local feature extraction is achieved through deep learning techniques, specifically using the MinkUNeXt (Cabrera et al., 2025) architecture, represented in Figure 2. This neural network is capable of embedding a 3D point cloud into a single 512-dimensional descriptor. It has been trained for the task of Place Recognition. The primary advantage of this network lies in its computational efficiency, which is facilitated by the use of 3D sparse convolutions. Given the nature of LiDAR scans, where information is sparsely distributed across 3D space, these layers allow the model to focus exclusively on regions containing points rather than processing empty voxels. The implementation of these sparse layers is supported by the Minkowski Engine library.

The MinkUNeXt architecture follows a U-Net topology, comprising two distinct sections: an encoder and a decoder. Within this framework, the input

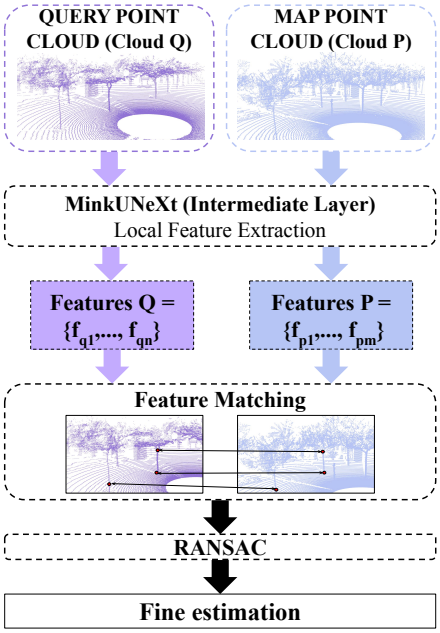


Figure 1: Schematic representation of the proposed fine localization framework. The process begins with the input of both a query scan (Cloud Q) and a reference map point cloud (Cloud P). Local features are then extracted from these scans utilizing the MinkUNeXt architecture, providing the basis for subsequent feature matching. Finally, the RANSAC algorithm is employed to estimate the 6DoF transformation matrix.

point cloud undergoes a progressive reduction in point density through the encoder stages, followed by a recovery of dimensionality within the decoder. This hierarchical structure facilitates multi-scale feature extraction. Furthermore, skip connections are implemented between the encoder and decoder layers to concatenate features acquired at different levels.

In this architecture, the encoder comprises five 3D Sparse Convolutions, while the decoder consists of three 3D Sparse Transposed Convolutions. Each convolutional layer is followed by Batch Normalisation and a ReLU activation function to normalise the descriptors. Furthermore, a MinkNeXt residual block is incorporated after each ReLU activation to facilitate high-level feature extraction.

Finally, the network includes a Fully Connected layer that projects the dimensionality of each descriptor to 512. This is followed by a Generalised Mean Pooling (GeM) layer, which aggregates the local features into a single global descriptor.

This paper presents a study of the intermediate layers of the network. Specifically, we analyse the performance of point cloud registration when utilizing descriptors extracted from each layer.

This analysis accounts for the variations in descriptor dimensionality and point cloud density across the network's intermediate outputs, which are expected to influence the results significantly.

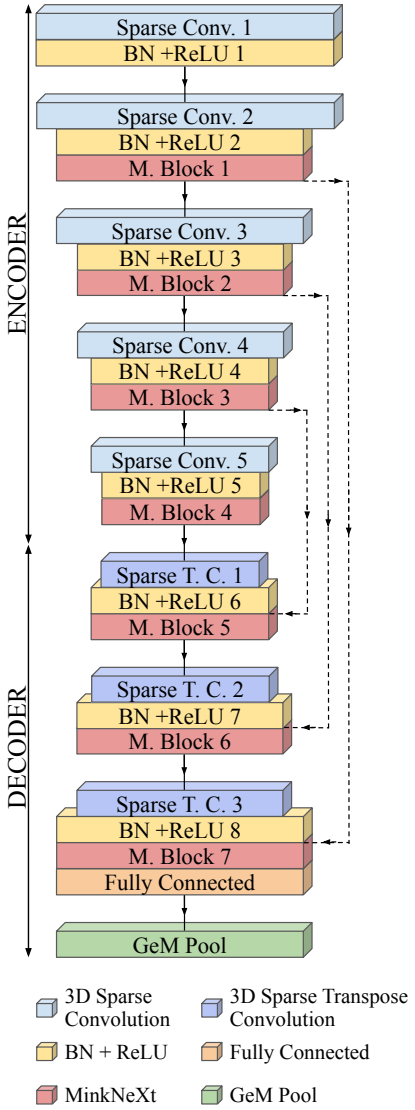


Figure 2: Architecture of MinkUNeXt network.

3.2 Point Cloud Registration

Point cloud registration is performed by taking two point clouds of the same scene, acquired from different poses and at different timestamps. The objective is to estimate the rigid transformation $T \in SE(3)$, comprising a rotation matrix R and a translation vector t, which aligns the scans and unifies them within a common coordinate system. In this study, the alignment process, illustrated in Figure 1, involves two point clouds Q and P, representing the query and the map, respectively. These are defined as sets of 3D points

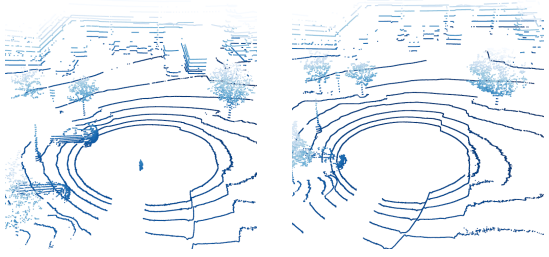
$q_1, q_2, ..., q_k$ and $p_1, p_2, ..., p_l$, where k and l denote the total number of points in each scan. Prior to registration, local descriptors are extracted, yielding the feature sets $f_{q_1}, f_{q_2}, ..., f_{q_n}$ and $f_{p_1}, f_{p_2}, ..., f_{p_m}$, where n and m are the new size of each point cloud. These features are subsequently employed to establish correspondences between the points based on their Euclidean distance in the feature space.

Finally, these matches and the original scans are processed by the RANSAC (Fischler and Bolles, 1981) algorithm to estimate the transformation matrix that relates both point clouds. While alternative robust estimation techniques, specifically PROSAC and USAC, were evaluated during this phase of the method, they were found to be less precise than the RANSAC implementation.

4 EXPERIMENTAL SETUP

4.1 Datasets

Different datasets have been selected to evaluate the proposed method. The map and the queries are composed of these data. There are several challenges in them because the data selected from the queries and the data used to create the map were captured at different times. For this reason, there are changes in dynamic elements, such as bikes or people, as we can see in Figure 3. Furthermore, the data and the map are captured in different months, so variability also arises from seasonal changes in vegetation and the presence of snow in some routes. Moreover, to test the method in different scenarios, we selected both indoor and outdoor environments. The data sources are the NCLT and UMH datasets.



(a) January. (b) June.

Figure 3: Point clouds captured at a similar position at distant times: (a) route 2012-01-08 and (b) route 2012-06-15, from the NCLT dataset.

NCLT (Carlevaris-Bianco et al., 2016): The University of Michigan North Campus Long-Term Vision and LIDAR Dataset contains information about this campus collected by the Segway robotic platform. For evaluating the proposed method, we utilized the LiDAR sensor from this dataset, specifically, the Velodyne HDL-32E LIDAR. The ground truth data utilized for our evaluation are provided within the dataset and were generated using SLAM techniques. To build the map we have used the data from the routes of January (2012-01-08, 2012-01-15, 2012-01-22), and for the queries we use the routes obtained in other months (2012-02-18, 2012-06-15).

UMH: This dataset (available in https://arvc.umh.es/db/databases/) contains information captured on the campus of Miguel Hernandez University of Elche with the robotic platform Husky A200. The point clouds that we use are captured with the Ouster OS1-128 LiDAR, and the ground truth poses are obtained with SLAM techniques. The routes used in this case are the route captured 2025-01-21-18-17-04 as the trajectory of the robot and the data from the map is obtained from the route 2024-04-24-12-47-35.

4.2 Implementation Details

For the evaluation process, LiDAR captures from distinct routes will be utilized to estimate their corresponding position and orientation using the aforementioned methodology. This will be achieved by comparing the query scan against a reference map scan captured during a temporally distinct month. In NCLT, we select reference scans acquired at a distance more than 10 meters from the query and exhibiting an orientation difference greater than 15 degrees. In the case of the UMH data, the distance is more than 5 meters and the orientation more than 10 degrees.

4.3 Evaluation Metrics

The evaluation metrics will quantify the degree of error between the predicted pose of the robot and its ground truth. To this end, the positional error is first evaluated as the Euclidean distance between the estimated position and the ground truth, with the mean and median of these values subsequently reported. Additionally, the orientation error is calculated as the absolute difference between the predicted and actual orientations, the mean and median of the resulting error dataset will be similarly presented.

5 RESULTS AND ANALYSIS

This section presents the quantitative and qualitative results derived from our methodology across the selected datasets. The experiments conducted are de-

tailed in Table 1. The analysis first assesses the network layers using the NCLT dataset, first a February trajectory (temporally aligned with the January map) and then a June trajectory. By doing so, the influence of different environmental disturbances can be studied independently. Specifically, Experiment 1 focuses on the effect of short-term dynamic changes, whereas Experiment 2 addresses the impact of long-term seasonal variations on the system's accuracy. The section concludes with the results obtained from the UMH dataset in Experiment 3 to evaluate the method's generalizability across other datasets.

Table 1: Experiments conducted during the evaluation of the proposed method.

Experiment	Dataset	Map Month	Query Month
Experiment 1	NCLT	January	February
Experiment 2	NCLT	January	June
Experiment 3	UMH	April	January

5.1 Results in NCLT Dataset

This section analyzes the performance of the local localization method using descriptors extracted from various layers of the MinkUNeXt architecture, evaluated on the NCLT dataset. The evaluation, Experiment 1, utilizes the February trajectory. Since the reference map was constructed using data from January, seasonal variations are minimal, however, the presence of dynamic elements, such as pedestrians and vehicles, poses a challenge for robust localization.

Table 2 details the pose estimation results for each layer of the network, illustrated in Figure 2. As shown in Table 2, there is a progressive and consistent reduction in both position and orientation errors as information flows through the layers of the network. Furthermore, the discrepancy between the mean and median, particularly pronounced in the orientation metrics of the early layers, indicates the presence of outliers or challenging cases that the network learns to mitigate as the depth increases.

Although metrics fluctuate between adjacent layers, an optimal performance interval is identified extending from MinkNeXt Block 4 to ReLU 7. This selection is justified because the minimum mean position error is achieved at the Sparse Transpose Convolution 1 layer (2.99 m), while the lowest median position error is recorded at the ReLU 7 layer (1.22 m), and regarding orientation, MinkNeXt Block 4 exhibits superior performance across both metrics, yielding a mean error of 9.07° and a median of 2.19°.

Since the median error is a robust metric against outliers, the stability of the median values within this range confirms that the network converges toward a consistent solution. This suggests that the performance is not a result of an isolated layer, but rather stems from a solid feature representation within the core of the architecture.

Conversely, the final layers exhibit a degradation in precision, potentially due to noise or overfitting, which negatively impacts feature extraction.

Consequently, these results demonstrate that the deepest layers of the encoder and the initial layers of the decoder capture the essential spatial information for effective feature extraction, resulting in precise pose estimation. This can be justified by examining the network structure: in the early layers, the network extracts low level geometric information, such as edges or corners, which lacks sufficient context of the complete point cloud. In contrast, at the end of the encoder, the point cloud reaches its maximum compression but contains rich semantic information, explaining the high performance in orientation.

However, as the resolution at this stage is limited, it is not until the up-sampling in subsequent layers that the point cloud partially recovers its resolution while maintaining semantic integrity, thus achieving the best results. In the final layers, although the original resolution is restored, the network may overfit to details associated with dynamic elements, leading to errors during the matching process.

Another noteworthy aspect is that the MinkNeXt blocks tend to significantly reduce or stabilize the error compared to the preceding simple convolutional layers. For instance, the transition from MinkNeXt Block 1 to Block 2 reduces the mean position error from 4.99 m to 3.97 m and the orientation error from 21.01° to 15.29°. This reveals the efficiency of these blocks in extracting highly relevant features.

To provide a qualitative assessment regarding Experiment 1, Figure 4 compares the February ground truth trajectory with the estimates generated by MinkNeXt Block 4. The deviation between the two trajectories is remarkably low, validating the reliability of the method.

Additionally, Figure 5 illustrates the impact of initial orientation misalignment on the final error. The system maintains low error in nearly all cases, even when the initial misalignment approaches 180°. While Table 2 shows that mean orientation errors exceed the medians, indicating a few outliers, Figure 5 confirms that the final orientation error remains low regardless of the initial misalignment.

Finally, experiments were conducted using a June trajectory. While Experiment 1 primarily assessed the method's robustness against dynamic environmental elements, Experiment 2 shifts the focus to long-term

Table 2: Mean and median error of the position and orientation obtained with different layers from the MinkUNeXt network in the February trajectory of the NCLT dataset. The best results are shown in bold.

	Position Error [m]		**Orientation Error [deg]**	
Layer	mean	median	mean	median
Sparse Convolution 1	7.63	7.72	37.16	10.22
BN+ReLU 1	7.51	7.63	39.68	9.71
Sparse Convolution 2	5.47	3.30	26.08	5.44
BN+ReLU 2	5.66	3.44	24.02	4.69
MinkNeXt Block 1	4.99	2.89	21.01	4.02
Sparse Convolution 3	5.02	2.46	19.40	3.78
BN+ReLU 3	5.01	2.27	19.85	3.48
MinkNeXt Block 2	3.97	1.70	15.29	3.20
Sparse Convolution 4	4.13	1.71	17.32	3.63
BN+ReLU 4	3.95	1.66	15.47	2.86
MinkNeXt Block 3	3.67	1.47	15.34	2.60
Sparse Convolution 5	3.32	1.38	11.41	2.53
BN+ReLU 5	3.21	1.44	11.91	2.50
MinkNeXt Block 4	3.13	1.34	**9.07**	**2.19**
Sparse Transpose Convolution 1	**2.99**	1.33	13.28	2.38
BN+ReLU 6	3.15	1.26	14.48	2.51
MinkNeXt Block 5	3.30	1.33	11.44	2.65
Sparse Transpose Convolution 2	3.07	1.37	13.01	2.35
BN+ReLU 7	3.14	**1.22**	13.02	2.82
MinkNeXt Block 6	3.12	1.25	10.54	2.46
Sparse Transpose Convolution 3	3.02	1.40	11.58	2.74
BN+ReLU 8	3.44	1.57	12.95	2.80
MinkNeXt Block 7	3.43	1.31	14.65	2.61
Fully Connected	3.20	1.30	12.69	3.04

Table 3: Mean and median error of the position and orientation obtained with different layers from the MinkUNeXt network in the NCLT dataset in June. The best results are shown in bold.

	Position Error [m]		**Orientation Error [deg]**	
Layer	mean	median	mean	median
MinkNeXt Block 4	**2.77**	**1.23**	10.27	2.51
Sparse Transpose Convolution 1	3.35	1.27	12.45	2.49
BN+ReLU 6	3.33	1.25	13.63	**2.45**
MinkNeXt Block 5	2.96	1.29	**10.24**	2.80
Sparse Transpose Convolution 2	3.60	1.42	12.71	3.18
BN+ReLU 7	3.25	1.38	13.03	2.77

Table 4: Mean and median error of the position and orientation obtained with different layers from the MinkUNeXt network in the UMH dataset. The best results are shown in bold.

	Position Error [m]		**Orientation Error [deg]**	
Layer	mean	median	mean	median
MinkNeXt Block 4	3.88	3.71	7.70	**1.89**
Sparse Transpose Convolution 1	3.97	3.75	7.48	2.82
BN+ReLU 6	4.05	3.93	**7.19**	2.64
MinkNeXt Block 5	**3.77**	3.83	10.55	2.43
Sparse Transpose Convolution 2	3.81	**3.63**	7.83	2.68
BN+ReLU 7	3.97	3.95	7.33	2.86

variations. By registering a June trajectory against a January reference map, we aim to demonstrate the robustness of our proposed approach against the significant seasonal changes introduced by such a substantial temporal gap. Based on the superior performance of intermediate layers observed in the February experiments, this analysis focused on these layers. The results, summarized in Table 3, demonstrate that the

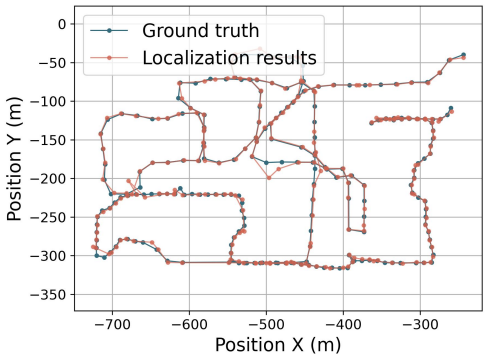


Figure 4: Trajectory from Experiment 1 with MinkNeXt Block 4, the ground truth locations (in blue) and the estimated position (in orange) are represented.

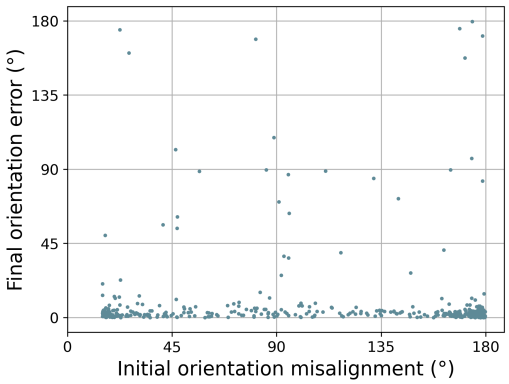


Figure 5: Representation of the impact of the initial misalignment on the final accuracy in orientation.

chosen layer range remains robust for localization, even in challenging environments. Furthermore, the evaluation confirms that feature extraction in these layers does not rely on specific seasonal conditions, rather, the network has learned a stable geometric and semantic representation of the environment.

In contrast to the February trajectory, MinkNeXt Block 4 achieved the best positional accuracy in June, yielding a mean error of 2.77 m and a median error of 1.23 m. This behavior suggests that in environments with substantial seasonal variations, the highly compressed semantic information provided by this bottleneck layer offers a more reliable solution than subsequent higher resolution layers, which may focus on seasonal noise, such as foliage or transient elements instead of stable structural features.

Regarding orientation, the error remains notably low. The lowest mean error was recorded in MinkNeXt Block 5 and the lowest median error in ReLU 6. These results are highly comparable to those obtained in MinkNeXt Block 4, which is the optimal layer in orientation in the February trajectory.

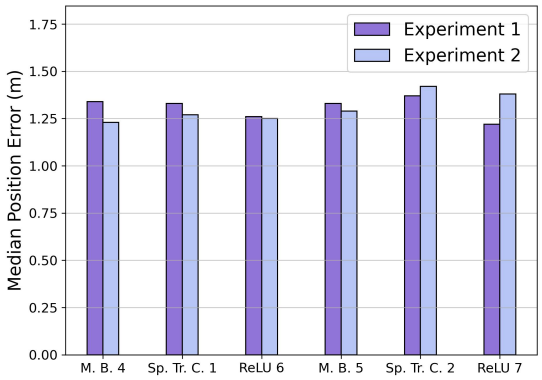


Figure 6: Comparison of the median position error between Experiments 1 and 2 within the optimal layer range.

Figure 6 compares the position results of Experiments 1 and 2. The comparable outcomes in both experiments confirm that dynamic and seasonal environmental disturbances affect the localization equally. Consequently, these findings highlight the inherent robustness of the proposed method within this specific layer range.

5.2 Results in UMH Dataset

In this section we present the results of Experiment 3, using the UMH dataset to evaluate the generalizability of the proposed localization method across different environments. This scenario introduces seasonal discrepancies, with a reference map generated in April and a query trajectory executed in January of the following year. In this case, we evaluate the intermediate layers due to their superior performance. The results are shown in Table 4.

Regarding orientation, the network demonstrates remarkable precision. MinkNeXt Block 4 achieves the lowest median orientation error of 1.89°, while ReLU 6 achieves the lowest mean error of 7.19°. This reaffirms the hypothesis that the bottleneck of the architecture captures a highly abstract, structural understanding of the scene, which is essential for accurate heading determination regardless of the dataset.

In terms of positional accuracy, the best metrics are obtained slightly later, during the initial upsampling stages. The lowest mean position error is achieved by MinkNeXt Block 5 (3.77 m), and the lowest median error is found at Sparse Transpose Convolution 2 (3.63 m). As demonstrated in Experiment 1 and Experiment 2, recovering a certain degree of spatial resolution via the early decoder layers is necessary to refine the positional alignment.

While the median positional errors in the UMH dataset are higher than those observed in the NCLT dataset, likely due to differences in the structural spar-

sity or sensor characteristics, the relative behavior of the network layers remains similar. This consistency demonstrates that the robustness of the intermediate layers is a fundamental property of the architecture, independent of the dataset used for evaluation.

6 CONCLUSIONS

This work presents an evaluation of the performance of the internal layers of the MinkUNeXt architecture to obtain the precise pose relating two captured point clouds, thereby achieving accurate local localization for a mobile robot. The proposed methodology was validated using two datasets: NCLT and UMH.

The analysis provides a detailed observation of the behaviour of each layer. We conclude that the intermediate layers exhibit superior performance compared to the rest of the architecture, specifically within the range extending from the final layer of the encoder (MinkNeXt Block 4) to the intermediate layers of the decoder (ReLU 7).

Furthermore, the alignment results demonstrated significant robustness. As evidenced by the NCLT February trajectory results, the method provides high accuracy even when evaluating trajectories captured at different timestamps with diverse environmental conditions. Additionally, the generalizability of the method was confirmed through its successful application to the UMH dataset, proving its effectiveness across different environments and sensor setups.

In summary, this study confirms that each layer extracts features that provide distinct levels of information. We conclude that for the task of pose estimation, research and implementation should focus on the intermediate layers, as they provide the optimal balance between semantic context and spatial resolution.

Future work will focus on integrating this strategy into a hierarchical localization pipeline, where a single forward pass provides both coarse retrieval and fine pose estimation, on its deployment on embedded platforms, and on its evaluation in environments subject to substantial structural modifications.

ACKNOWLEDGEMENTS

This research work is part of the project PID2023-149575OB-I00 funded by MICIU/AEI/10.13039/501100011033 and by FEDER, UE. Furthermore, it is part of the project CIPROM/2024/8, funded by Generalitat Valenciana, Conselleria de Educación, Cultura, Universidades y Empleo (program PROMETEO 2025).

REFERENCES

Alfaro, M., Cabrera, J. J., Gil, A., Reinoso, O., and Payá, L. (2026). PDPR: Panoramic-depth place recognition through the fusion of visual and geometric-aware features. *Neurocomputing*, 677:133112.

Besl, P. J. and McKay, N. D. (1992). Method for registration of 3-D shapes. In *Sensor fusion IV: control paradigms and data structures*, volume 1611, pages 586–606. Spie.

Cabrera, J. J., Santo, A., Gil, A., Viegas, C., and Payá, L. (2025). MinkUNeXt: Point cloud-based large-scale place recognition using 3D sparse convolutions. *Array*, 28:100569.

Carlevaris-Bianco, N., Ushani, A. K., and Eustice, R. M. (2016). University of Michigan North Campus Long-Term Vision and Lidar Dataset. *The International Journal of Robotics Research*, 35(9):1023–1035.

Chen, Y. and Medioni, G. (1992). Object modelling by registration of multiple range images. *Image and vision computing*, 10(3):145–155.

Choy, C., Park, J., and Koltun, V. (2019). Fully Convolutional Geometric Features. In *Proceedings of the IEEE/CVF international conference on computer vision*, pages 8958–8966.

Fischler, M. A. and Bolles, R. C. (1981). Random sample consensus: a paradigm for model fitting with applications to image analysis and automated cartography. *Communications of the ACM*, 24(6):381–395.

Garcia, G. and Eskandarian, A. (2025). Point Cloud Registration for Visual Geo-Referenced Localization Between Aerial and Ground Robots. In *Proceedings of the 22nd International Conference on Informatics in Control, Automation and Robotics - Volume 2: ICINCO*, pages 211–218. INSTICC, SciTePress.

Luo, L., Cao, S.-Y., Li, X., Xu, J., Ai, R., Yu, Z., and Chen, X. (2025). BEVPlace++: Fast, Robust, and Lightweight LiDAR Global Localization for Autonomous Ground Vehicles. *IEEE Transactions on Robotics*, 41:4479–4498.

Schaupp, L., Bürki, M., Dubé, R., Siegwart, R., and Cadena, C. (2019). OREOS: Oriented Recognition of 3D Point Clouds in Outdoor Scenarios. In *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 3255–3261. IEEE.

Segal, A., Haehnel, D., Thrun, S., et al. (2009). Generalized-ICP. *Robotics: science and systems*, 2(4):435.

Vilella-Cantos, J., Martini, M., Chiaberge, M., Ballesta, M., and Valiente, D. (2026). Low Cost, High Efficiency: LiDAR Place Recognition in Vineyards with Matryoshka Representation Learning.

Zhang, Y., Shi, P., and Li, J. (2024a). 3D LiDAR SLAM: A survey. *The Photogrammetric Record*, 39(186):457–517.

Zhang, Y.-X., Gui, J., Cong, X., Gong, X., and Tao, W. (2024b). A Comprehensive Survey and Taxonomy on Point Cloud Registration Based on Deep Learning. In *IJCAI*, pages 8344–8353.

Zhou, Q.-Y., Park, J., and Koltun, V. (2016). Fast Global Registration. In *European conference on computer vision*, pages 766–782. Springer.