Research Achievement: Geometric Cybernetics for Machine Learning and Quantum Computing

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Overview

Prof. Dr. Bayro-Corrochano is an internationally recognized scholar and a leading authority in the field of Geometric Cybernetics. His research is centered on the rigorous development and application of Clifford geometric algebra as a unified, coordinate-free mathematical framework for perception and action systems.

His work advocates the formulation of geometric concepts and physical constraints through coordinate-free algebraic expressions, enabling high-level geometric reasoning. In conventional coordinate-based algebraic computing, results often lack intrinsic geometric meaning because they are neither invariant nor covariant under coordinate transformations. In contrast, geometric algebra encodes geometric information through geometric products and operator actions that remain independent of the choice of reference frame. This framework permits the formulation of robotics physics and related systems without reliance on indices or coordinate representations, thereby providing a level of conceptual clarity that is typically obscured in matrix or tensor algebra.

Theoretical Contributions and Methodological Innovations

Prof. Bayro-Corrochano's research encompasses the theoretical advancement and practical implementation of Clifford geometric algebras across a wide spectrum of disciplines, including pattern recognition, image processing, computer vision, artificial intelligence, neurocomputing, machine learning, control theory, robotics, and quantum computing.

Among his pioneering contributions are:

- The formulation of the Geometric Multilayer Perceptron (MLP) within a Clifford algebra framework.
- The development of Clifford Support Vector Machines.
- Quaternion-based quantum neural networks and quaternion spiking neural networks for pattern recognition and neuro-control.

- The Quaternion Wavelet Transform and Quaternion Fourier Transform grounded in space–time metric structures.
- The Quaternion Fractional Fast Fourier Transform (FFT) and Quaternion Quantum FFT for advanced color image processing.
- Quantum Computing & Machien Learning

He has also introduced novel interpolation methodologies for geometric entities—such as lines, planes, circles, spheres, and hyperplanes—based on motor algebra (SE(3)) and Bézier constructions defined on the Study manifold. These developments provide mathematically consistent and geometrically meaningful solutions for motion representation and robotic trajectory generation.

Within geometric algebra, his contributions further extend to:

- Kinematics and dynamics formulated in Clifford algebra.
- Recursive Euler–Lagrange and Newton–Euler algorithms.
- Port-Hamiltonian system representations.
- Phase-space computation via the Koopman operator.
- Physical Informed Neural Networks: Eikonal Neural Solver for path planning of robot arms using Riemannian geometry.

These contributions have had a substantial impact on nonlinear control theory, particularly in robot vision and advanced robotic systems. He has also strongly promoted the formalization of geometric quantum computing within the Clifford algebra framework.

Quantum Computing and Machine Learning

1. I am a contributing author of the monograph *Geometric Algebra Applications, Volume III: Integral Transforms, Machine Learning, and Quantum Computing* (Springer, 2024, out of 8 of my books), to which I contributed four chapters. This books is out of 8 books.Eight of these chapters are specifically devoted to the mathematical foundations of quantum computing, advanced geometric methods, machine learning and quantum computing applicable to general quantum computation. The volume is suitable for both first- and second-level programs in Quantum Computing and researchers.
2. I have authored at least six peer-reviewed journal articles in the field of quantum computing.
3. I have been invited as an opening or keynote speaker at several international conferences, including:
    - Quantum Informatics, Computing & Technology 2025 (QC–HORIZON 2025), Pilsen, Czech Republic (August 26–27, 2025).
      Keynote: *Quantum Computing, Machine Learning, and Geometric Algebra for Signal and Image Processing*.
    - SPA 2025 – Signal Processing Conference, Poznań, Poland (September 17–19, 2025).
      Opening lecture: *Quantum Computing, Machine Learning, and Geometric Algebra for Signal and Image Processing*.

- RAAD 2026 – 35th International Conference on Robotics in the Alpe-Adria-Danube Region, Bratislava, Slovakia (June 17–19, 2026).
  Opening lecture: *Geometric Algebra and Quantum Computing for Robot Modelling and Control*.

Geometric Cybernetist

Professor Eduardo Bayro is a Geometric Cybernetist whose research establishes a unified geometric foundation for the analysis, modeling, and control of complex physical, biological, and artificial systems. His work is centered on the systematic application of Geometric (Clifford) Algebra as a coordinate-free and structurally consistent mathematical framework for analytical mechanics, Hamiltonian systems, nonlinear dynamics, robotics, artificial intelligence, neurocomputing, medical robotics, and quantum computation.

His scientific program aims to integrate geometry, dynamics, and intelligence within a coherent theoretical architecture. By reformulating kinematics, dynamics, and control theory in geometric terms, he advances invariant representations of motion and interaction, enabling robust mathematical modeling of humanoid robotics, neural systems, and intelligent autonomous agents. In medical image processing and medical robotics, he develops geometrically grounded computational methods for precise analysis and intervention.

Through this interdisciplinary yet mathematically rigorous approach, Professor Bayro contributes to the development of Geometric Cybernetics as a unified paradigm bridging analytical mechanics, nonlinear control, computational intelligence, and emerging quantum technologies. His research is documented in multiple monographs and peer-reviewed publications, reflecting a sustained commitment to advancing geometry as a foundational language of modern science and engineering.

Scholarly Publications

His scientific contributions are prominently represented in three major volumes (out of eight books) published by Springer:

- *Geometric Algebra Applications: Vol. I – Graphics, Computer Vision and Neurocomputing* (2018).
- *Geometric Algebra Applications: Vol. II – Robot Modelling and Control* (2019).
- *Applications of Geometric Algebra: Vol. III – Integral Transforms, Deep Learning and Quantum Computing* (2024).

These volumes serve as foundational references for MSc and PhD-level instruction and constitute significant scholarly resources for researchers and practitioners in cybernetics, robotics, and computational intelligence.

Technological Developments and Engineering Contributions

Between 2012 and 2018, Prof. Bayro-Corrochano led the design and construction of the Mexican humanoid robot "MEXONE," a pioneering development in Latin America. Additionally, between 2012 and 2017, he developed a second humanoid platform, "CINVESROB" (165 cm height, 28 degrees of freedom), in collaboration with PAL Robotics (Barcelona, Spain).

Other high-impact technological innovations include:

- A lens-based assistive navigation system for visually impaired individuals.
- Intelligent robotic hands and feet for persons with disabilities.
- A smart robotic system for three-dimensional inspection of water pipelines.

These developments demonstrate the translation of theoretical geometric computing frameworks into practical robotic and assistive technologies.

Editorial Leadership and Professional Recognition

Prof. Bayro-Corrochano has served as Associate Editor of *IEEE Transactions on Neural Networks and Learning Systems* and *Journal of Mathematical Imaging and Vision*, and is a member of the editorial boards of *Pattern Recognition* and *Robotica*.

His contributions have been recognized with the First Prize in Science and Technology awarded by the State of Jalisco, Mexico, in 2003 and 2009. He is a Fellow of the International Association of Pattern Recognition (IAPR), a Senior Member of the IEEE, and a member of the Administrative Committee of the IEEE Robotics and Automation Society (RAS), serving as Representative for GEO Area 1.

He has also held prominent leadership roles in major international conferences, including:

- General Chair, International Conference on Pattern Recognition (ICPR 2016), Cancun, Mexico.
- **General Chair, IEEE/RAS Humanoids 2016, Cancún, Mexico.**
- **General Chair, IEEE/RAS International Conference on Robotics and Automation (ICRA 2028), Guadalajara, Mexico.**