

Research Statement

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1. Core Research Philosophy & Vision

My research lives at the intersection of **Advanced Control Theory, Robot Kinematics, and Human-Robot Interaction (HRI)**. The overarching objective of my work is to translate complex mathematical and biomechanical formulations into fluid, deployable, and human-aware software stacks for collaborative autonomous systems.

As robotics transitions from isolated industrial cages into complex shared human workspaces, standard trajectory generation algorithms fail because they treat human agents as static obstacles. My research framework challenges this paradigm by formulating unified control loops where the manipulator actively interprets, models, and adapts to human physical and visual movement patterns in real time. Over the past five years, I have systematically scaled this vision across three primary axes: low-level force compliance control, high-frequency recursive parameter estimation, and multi-modal human spatial negotiation models.

2. Foundational Research & Key Contributions

A. Multi-Agent Hybrid Position/Force Compliance Control (Master's Trajectory)

During my research at Istanbul Technical University (ITU), I focused on the problem of continuous physical contact inside multi-agent systems. I developed mathematical formulations for closed-kinematic chains, mapping task-space load allocation matrices directly onto redundant actuator spaces. This allowed multiple manipulators to safely distribute contact forces while managing environmental constraints. I verified these models empirically across physical multi-axis platforms, laying the groundwork for safe, force-compliant human-robot interaction loops.

B. High-Frequency Recursive Parameter Tracking (JIRS 2024)

A significant bottleneck in model-based adaptive robot control is the extreme computational overhead required to calculate high-dimensional regressor matrices online. To address this limitation, I engineered an alternative recursive parameter tracking algorithm derived from inverse Newton-Euler formulations.

- **The Core Metric:** By systematically bypassing explicit regressor building parameters, the computational complexity scales linearly with the number of links, entirely avoiding matrix inversion latency.
- **Outcome:** This work, published in the *Journal of Intelligent & Robotic Systems*, proved that adaptive control loops can be scaled to high iteration frequencies on standard production microprocessors, drastically reducing trajectory tracking lag on physical arms.

C. Mathematical Modeling of Motor Interference (Interaction Studies 2026)

To understand how humans adjust to proximity-based automation, I conducted extensive multi-modal human trial runs tracking visual gaze patterns, task-space error rates, and human joint kinematic adjustments.

- **The Invention of DAV:** Traditional tracking metrics routinely conflate intentional human task paths with accidental control noise. To solve this, I formulated a novel computational metric called **Distractor-Aligned Variance (DAV)**, which isolates trajectory variations strictly orthogonal to the running task

vector $\mathbf{x}(t)$:

$$\text{DAV} = \frac{1}{T} \int_0^T \|\mathbf{e}(t) - (\mathbf{e}(t)^T \hat{\mathbf{v}}_d(t)) \hat{\mathbf{v}}_d(t)\|^2 dt$$

- **Outcome:** Published in *Interaction Studies*, this mathematical pipeline successfully demonstrated that a robot's internal null-space configurations (e.g., changing elbow orientations without moving the end-effector) trigger sub-conscious, involuntary biomechanical path updates in nearby human operators.

3. Current Focus: Hierarchical Motion Planning (DFG CoSMoC Project)

Currently, as a Doctoral Associate within the DFG-funded **CoSMoC Project** (Grants: *KU 2486/9-1, 8-1, 8-2*), I am bridging my biomechanical interference models with high-level software architectures. I am architecting a hierarchical, congruency-sensitive C++/Python motion-planning framework that runs natively inside a ROS 2 middleware stack on collaborative hardware platforms (Franka Emika Panda, UR3).

This framework utilizes inverse optimal control and online dynamic state estimation to interpret human task sequences. Instead of standard reactive braking, the planning engine utilizes the DAV signal as a direct feedback primitive, modifying costmap weights online to proactively synthesize trajectory orientations that match human cognitive sightlines. Concurrently, to support multi-platform flexibility, I have expanded my focus to Autonomous Mobile Robots (AMRs), deploying custom laser SLAM pipelines and ROS 2 Nav2 configurations across AgileX Scout Mini and TurtleBot 4 platforms to govern autonomous navigation loops.

4. Future Research Agenda (Next 3–5 Years)

Looking forward, my goal is to lead a dedicated research track focused on **Cognitively-Congruent Trajectory Optimization for Shared Workspaces**. I plan to build on my DFG framework by pursuing external research grants (such as EU Horizon, DFG individual grants, or NSF/NIH tracks depending on institutional alignment) to explore three high-impact domains:

Theme I: Multi-Modal Human Intention Primitives for Predictive Trajectory Synthesis

Current predictive planners rely heavily on low-dimensional tracking inputs (e.g., wrist position). I intend to build robust sensor-fusion loops that merge wide-area LiDAR, skeletal tracking, and wearable IMU data directly into probabilistic trajectory models. By mapping these inputs into real-time trajectory optimization frameworks like TrajOpt or Movelt, the collaborative robot will synthesize fluent evasive path motions meters before a physical collision boundary is reached.

Theme II: Decentralized Control and Navigation for Heterogeneous AMR-Manipulator Fleets

Building on my recent ROS 2 Nav2 and manipulator setups, I will investigate the coupling between mobile bases and robotic arms working together. This involves developing distributed, model-predictive control (MPC) loops that coordinate mobile base mobility with arm manipulator tracking metrics, enabling fluid, non-stop mobile manipulation in dynamic environments like collaborative manufacturing or logistics warehouses.

Theme III: Standardizing Cognitive Safety Benchmarks for Industrial Human-Robot Interaction

While physical safety protocols are strictly regulated by ISO standards, cognitive safety metrics are virtually non-existent. I aim to establish the Distractor-Aligned Variance (DAV) algorithm as an industry-standard benchmark for certifying the behavioral safety of collaborative software stacks, creating a public, open-source testing platform that allows teams to validate planning algorithms against real human behavioral response metrics.

5. Contextual Integration & Mentorship Commitment

My research methodology is deeply anchored in **empirical reproducibility**. Every theoretical framework I map out is validated by open-source codebases and direct hardware demonstrations on physical systems. Beyond my individual research, I am deeply committed to academic mentorship. Having served as an Associate Editor and Program Committee reviewer for major robotics tracks (IEEE ARSO, RO-MAN, ICSR), and having taught advanced control engineering lab sections, I intend to actively foster a collaborative lab environment where undergraduate and master's students can easily compile, debug, and execute complex control loops on real-world robotic hardware.