The rapid progress in robotics is reshaping what machines can do, from autonomous drones soaring through the skies, to robot vacuums navigating our homes, and even agile legged robots tackling complex terrains. Behind these astonishing advancements lies a crucial ingredient: cutting-edge fundamental research in control techniques—the science of making machines move and behave as desired. Without this basic research in control theory, these robotic marvels would remain science fiction.

This project focuses on refining and expanding a particular approach in this field: feedback linearization methodologies for mechanical control systems. Mechanical control systems, which describe the dynamics of many machines, often present engineers with a tough challenge: their behavior is governed by intricate and nonlinear differential equations. Such complexity makes designing effective control systems difficult. However, feedback linearization techniques simplify these problems by transforming nonlinear behaviors into forms that align with well-understood linear control methods. Despite their promise, control techniques based on feedback linearization are underutilized due to gaps in implementation. This project aims to bridge that gap, developing new tools and approaches to streamline control design. By doing so, we hope to make these techniques more accessible and practical, unlocking their potential for broader application in industries ranging from robotics to aerospace.

Research Tasks Summary:

Linearizing Mechanical Systems with Dissipation. We explore methods to simplify (linearize) nonlinear mechanical systems by transforming them into a more predictable, linear form while preserving their inherent mechanical structure. Focusing on a class of mechanical control systems that dissipate energy over time, we utilize advanced mathematical tools from differential geometry (such as Lie brackets, distributions, the covariant derivative, and the curvature tensor). These tools reveal the underlying linear nature of the system, forming a theoretical framework for the systematic design of control laws.

Input-Output Linearization and Handling Disturbances. In this task, we continue our research on the linearization of mechanical systems, this time focusing on input-output linearization. We also address the disturbance decoupling issues, aiming to mitigate the influence of disturbances (like vibrations, noises, or unwanted external forces), which are unavoidable in practice.

Coupling of Multi-Agent Systems. We study the coupling of multiple interacting mechanical systems, such as drones or robotic teams, to enable the synthesis of control strategies for the entire formation. To achieve this, we leverage the properties of differential flatness, implemented through noninvertible feedback action between agents.

Enhancing Practicality - Globalization. This task focuses on refining linearization techniques to tackle a control problems, such as maintaining system stability, efficiently moving from one point to another, or following a precise trajectory. Local solutions, often poorly performing, are enhanced by "gluing" them together into a control that works in wide operational range.

AI-Enhanced Control for Uncertain Systems. To address situations where system behavior is complex and poorly understood, we leverage artificial intelligence, particularly neural networks, to estimate and adapt feedback control law strategies in real time.

Combining Theory and Practice

Each task balances theory, practical tool development, and hands-on experiments using simulations and lab equipment. It includes a theoretical phase to develop mathematical foundations, an application phase to create tools, and an exemplification phase to validate solutions, ensuring innovations work both in theory and practice.

Impact and Vision

The outcomes of this project will significantly impact both the academic and practical realms of control engineering, as well as the broader discipline of control theory. By developing new knowledge and refining existing techniques, the project aims to enrich academic discourse, inspire further research, and pave the way for innovations across industries.