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Report concerning the manuscript of Marcin Nowicki:
Feedback Linearization of Mechanical Control Systems

In his manuscript Marcin Nowicki investigates linearization of a sub-class of control systems widely used in robotics, holonomic mechanical systems. He formulates feedback linearization of mechanical control systems merging differential geometric concepts and objects with non-linear control mathematical methods. Here a mechanical control system is seen as set of four objects $(Q, \nabla, \mathfrak{g}, e)$: Q a finite dimensional manifold, ∇ a symmetric affine connection on Q, $\mathfrak{g}$ a finite collections of control vector-fields on Q and e a fixed vector field on Q. This point of view is original and the starting point of several new and elegant mathematical results with convincing applications in robotics.

Following a first introduction chapter, chapter 2 starts with a tutorial presentation of manifold, tensor fields and Riemannian objects. In particular, Theorem 2.11 characterising flat symmetric affine connections (their Christoffel symbols vanish in an appropriate configuration coordinates) will be instrumental for potential reformulation and extension of well-established linearization results. These results are recalled in the second part of this chapter for affine control systems (state-space and static feedback linearization) with their relationships to linearizing or flat outputs, inversion and decoupling.

In chapter 3, Marcin Nowicki details his original notion of mechanical control systems based on the key role play by a symmetric affine connection on Q. He shows how this definition is inspired from the Lagrange equations of an holonomic mechanical system. The symmetric affine connection coincides then with the Levi-Civita one derived from the Riemannian structure attached to the kinetic energy. This notion is then illustrated by several robotics systems those control will be investigated through numerical simulations in the last chapter.

Chapter 4 is devoted to linear mechanical control systems. Here Marcin Nowicki characterizes linear mechanical systems that are mechanical feedback equivalent. He shows that this more restrictive notion of equivalence based on a smaller group, is in fact identical, for linear mechanical systems, to usual linear feedback equivalence of general time-invariant linear systems. This results is interesting. It is illustrated on a coupled spring-mass system inspired of a space discretization of a wave equation with boundary control.

In chapter 5, Marcin Nowicki starts with the notion of mechanical state-space equivalence which admits a very concise formulation with the $(Q, \nabla, \mathfrak{g}, e)$ definition. With theorem 5.6, Marcin Nowicki formulates a very elegant characterisation of mechanical control systems equivalent, via configuration coordinate changes, to a linear mechanical system whatever its controllability is: the curvature tensor, the total covariant derivatives of the control vector fields and the second total covariant derivative of the fixed vector field should vanish.

In chapter 6, Marcin Nowicki enlarges the classification group with mechanical feedback transformations acting on mechanical control systems. This leads to the notion of mechanical feedback equivalence with also a concise definition. Similarly to theorem 5.6, Marcin Nowicki proposes in theorem 6.21 an elegant characterisation of mechanical systems equivalent to linear ones. This theorem is the most important mathematical achievement presented by Marcin Nowicki in his manuscript.

Chapter 7 begins with a direct application of theorem 6.21 to the inertia wheel pendulum and cart-pole systems, systems with two degrees of freedom for which the invariant characterization of theorem 6.21 simplifies. Then Marcin Nowicki tackles robotics control problems (typically, feedback stabilization with pole placement, motion planing and trajectory tracking) for three examples: an inertia wheel pendulum, a translational oscillator with rotational actuator and a single link manipulator with joint elasticity. For theses mechanical systems Marcin Nowicki constructs, from their mechanical feedback linearization and linearizing output, motion planing and stabilizing feedback algorithms. The parametric robustness of these algorithms are then tested on closed-loop simulations (MatLab Simulink simulations). This last chapter illustrates clearly the practical interest of the mathematical methods and results presented in the previous chapters.

This manuscript is well written and organized. It shows the ability of Marcin Nowicki to master the state-of-the-art and presents original contributions to nonlinear control problems with important applications. *To conclude, I feel very comfortable to claim that the manuscript of Marcin Nowicki satisfies all academic requirements referring to the doctoral dissertations in the field of Engineering and Technology, discipline Automation, Electronics and Electrical Engineering. I recommend its admission to the public defense.*

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