

## Lie Bracketing for Investigating Singularities of holonomic and nonholonomic Robots

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**Abstract:** The pose of a robot is represented by a point on a manifold defined by certain constraints, and the robot motion is the motion of its representing point on this manifold. To understand the motion capabilities in a neighborhood of a given pose one looks at velocity vector fields and investigates the associated flow. The point of departure is a system of Pfaffian constraints defining a codistribution in  $SE(3)$ . For linkages comprising lower pair joints, the latter is always integrable (in Pfaffian sense), and the local geometry of the solution variety is described by the tangent cone. The defining equations of the latter are given in terms of Lie brackets of joint screws. For nonholonomic robots, e.g. mobile platforms, the constraints are not integrable. A key object to decide about controllability of nonholonomic robots is the filtration of the constraint distribution defined by nested Lie brackets. The situation becomes much more complicated if the robot reaches a singularity. Still the tangent cone can be computed and serves as a valuable tool for investigating singularities of linkages. For nonholonomic robots, inferring possible motions and controllability in a singularity is not as straightforward. Moreover, there is no well-established notion of kinematic singularities of nonholonomic robots. Investigating possible motions would boil down to investigate integrability of singular codistributions.

In this talk, a unified definition of singularities of serial robotic manipulators and nonholonomic robots is presented, which is based on the filtration of the controllability distribution. The concept of kinematic tangent cone for the analysis of local motion capabilities of lower-pair linkages is recalled, and the computation in terms of Lie brackets of the joint screws is explained.