# CONTROL OF A QUADROTOR/BICOPTER UAV ON SE(3) VIA FEEDBACK LINEARIZATION

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## INTRODUCTION

A major challenge in controlling multirotor UAVs, including quadrotors and bicopters, is due to their nonlinearity, where feedback linearization can help mitigate this problem and allow linear control techniques to be applied. Indeed, there are attempts to linearize quadrotor and bicopter dynamics, but as far as the authors are aware, no existing work has been developed directly on SE(3) like a geometric controller, which makes those control systems prone to singularities and ambiguities associated with local coordinates. Not to mention, some of the work assumes small angle and/or uses linear approximation, which further limits the operating range of those controllers.

The renowned, almost globally exponentially attractive [1], geometric controller follows a cascade control structure, where its exponential stability requires the initial attitude error to be less than 90 degrees and its inner, nonlinear attitude controller contains an unstable equilibrium point.

In this work, via feedback linearization, a unified position controller and a separate yaw controller are proposed for trajectory tracking purposes. The unified position controller eliminates the need for an inner controller and is in theory globally exponentially stable with non-zero input thrust being the only constraint, i.e. not in free fall. Similarly, this also removes the unstable equilibrium point in the yaw controller and results in global exponential stability.

## METHODS

The underlying concept of feedback linearization is to algebraically transform a nonlinear system into a linear one [2]. This differs from Jacobian linearization or linear approximation, in that feedback linearization is achieved by exact state transformation and feedback.

After feedback linearization, virtually every control law, including linear quadratic regulator/integral, can be applied to the resulting linear system.

In this work, backstepping, which is a recursive approach that integrates the selection of a Lyapunov function with feedback control design, i.e. a Lyapunov-based design [3], was chosen due to its flexibility and intuitive nature.

Although it is common to assume the motor dynamics is negligible for most UAV applications, in this work, an inner controller to account for the motor dynamics is designed to improve the overall tracking performance.

## RESULTS AND DISCUSSION

With feedback linearization, well-established analysis and control techniques for linear systems can be applied to design a trajectory tracking control system.

Hence, with rigorous Lyapunov analysis, it is shown that, departing from a cascade control structure, the proposed unified position controller results in global exponential stability under a nominal condition, which is regarded as the strongest form of stability.

The simulation result shown in (Fig 1) confirms that the performance of the proposed controller is superior to the renowned geometric controller in [1].

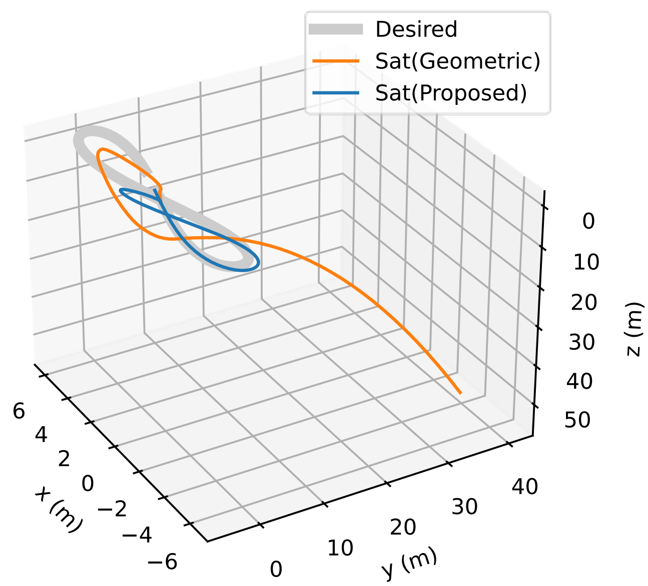


**Fig 1** Quadrotor Tracking a Figure "8" Shape with Saturation.

Meanwhile, being developed directly on SE(3), the proposed controller is also free from singularities and ambiguities inherent in other attitude representations. The result includes an inner motor controller, an adaptation law and an optimization algorithm as well.

## CONCLUSIONS

In summary, feedback linearizing the dynamics of a quadrotor and a bicopter directly on SE(3) is the key contribution of this work. This alleviates the challenges of working with a nonlinear system and is free from singularities and ambiguities. Meanwhile, the proposed controller is in theory globally exponentially stable, which non-zero input thrust is the only restriction.

## REFERENCES

[1] Lee T et al. *49th IEEE CDC*, 2010.
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