The Cooper Union
ME457 - Drone Control
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Thoughts on INDI Controllers:

This is not an in depth proposal by any means, but I felt like it'd be nice to tack onto our final submission just to show that we thought about it.

MAVs are governed by "a fairly complicated set of 12 nonlinear, coupled, first-order, ordinary differential equations". One of the primary goals of Randal Beard's textbook is to linearize and decouple these equations to develop linear design models so we can progress to autopilot design, estimating states, etc. A notable consequence of this linearization is that we can utilize conventional PID or lead-lag compensators.

PID controllers are very cool. They're scalable, easily implementable, and relatively simple to tune for students new to controller design. They're also very cost efficient. However, because PID controllers aren't model-based (which means you don't need to know the actual dynamic behavior of the process to implement them), they don't perform nearly as well in response to heavy disturbances as some alternatives. Beard himself notes that the utilization of PID controllers is contingent on the plant models being first- or second-order near the end of §6.1.

Let's switch gears and take a look at another control technique - Nonlinear Dynamic Inversion (NDI). NDI, in contrast to the aforementioned linear schemes, is extremely model-dependent. In a nutshell, it calculates the dynamic loads necessary to control the process in a desired manner, and applies the opposite, "cancelling" them out. This bypasses the guesswork of PID control, but creates the opposite problem - we need to know all aspects of the process in order to anticipate conditions. Since we also have to deal with the intrinsically unsteady nature of MAV flight and the impracticality of perfect sensors, using NDI seems less appealing despite its potential as a disturbance rejection king.

That's where Incremental Nonlinear Dynamic Inversion (INDI) comes in. INDI reduces the pixel precision required for NDI by using the MAV's acceleration feedback from accelerometers to find the dynamic behavior in response to disturbances. This eliminates the guesswork that comes with a model capable of handling unpredictable wind disturbances, as the controller can simply use the accelerometer readings rather than estimating the acceleration at any point in time. The flight controller incrementally finds the delta between the actual acceleration of the MAV and the desired acceleration, and responds by changing the motor speed.

INDI isn't perfect; it's not even close. It's kind of a pain to implement, and while it's an improvement on NDI, it's still very dependent on the accuracy on the MAV model. However, its potential in challenging wind conditions makes it a compelling control technique to experiment with. I'm also curious how its benefits correlate with the size of the MAV itself.

My initial proposal on Monday was to compare Crazyflie's implementation[1] of the INDI attitude rate controller and a conventional cascaded PID controller setup (both optimally tuned) in a wind tunnel and see which one rejected simulated disturbances better. However, I looked for a few videos and a nearly identical experiment was run at TU Delft a few years ago.[2] Nevertheless, it would be fun to experiment with less standard controller types at some point; I'll come up with some new ideas next semester.

[1] See here!
[2] Here's a video.