

Nonlinear Robust H-Infinity PID Controller for the Multivariable System Quadrotor

J. P. Ortiz, *Member, IEEE*, L. I. Minchala, *Member, IEEE* and M. J. Reinoso

Abstract— This paper presents the methodology of design of a nonlinear robust controller for attitude regulation and its implementation in an experimental platform of an unmanned aerial vehicle (UAV) quadrotor. Details on the kinematic and dynamic modeling based on the Euler-Lagrange formalism are provided, as well as the particulars of the design of a nonlinear robust H-infinity PID controller to regulate the rotational moments. The performance and effectiveness of the proposed controller are tested in a simulation and an experimental platform. The performance of the proposed controller is compared with a conventional PID controller by using the integral square error (ISE) as performance parameter. Experimental results help to demonstrate the correct operation of the system for real-time applications in the presence of unmodeled dynamics and the uncertainties of the parameters.

Keywords— Nonlinear system, quadrotor, robust control, attitude regulation, UAV

I. INTRODUCCIÓN

LOS sistemas de control para vehículos aéreos no tripulados del tipo quadrotor se han desarrollado con gran rapidez en los últimos años. La necesidad de desarrollar sistemas con mayor autonomía, que puedan realizar maniobras de alta complejidad, que realicen misiones de largo alcance, que operen en entornos de alto riesgo para los seres humanos, sin duda han permitido que este campo este bajo continua investigación y desarrollo [1-3].

En [4] se establece un controlador robusto para despegue, seguimiento de trayectoria y aterrizaje, constituido por un controlador de posición y un controlador de orientación. El controlador de posición usa el método de realimentación estática para obtener la altura deseada, mientras que el control de orientación utiliza un proporcional-derivativo (PD) con una técnica de compensación robusta. En [5] se propone agregar a la estructura del controlador PD un método robusto de sintonización de parámetros, que permite modificar en línea los parámetros del compensador durante el seguimiento de una trayectoria.

Los estudios realizados en [6] plantean un controlador robusto no lineal H_{∞} para estabilizar los momentos de rotación y un control basado en el enfoque de *backstepping* para el seguimiento de trayectoria. La referencia [7] sugiere un controlador del tipo integral predictivo para resolver el problema de seguimiento de trayectoria. Ambos resultandos simulados son robustos ante perturbaciones externas del sistema.

En [8] se propone un controlador tolerante a fallas para planeamiento y re-planeamiento de trayectorias. En [9] se implementan y comparan dos algoritmos de control tolerante a fallas basados en: un regulador lineal cuadrático y un controlador de modelo predictivo, los resultados demuestran un desempeño aceptable de los algoritmos para el control de altura en presencia de pérdidas parciales de la acción de los actuadores.

Diversas investigaciones [10-12] han realizado comparaciones entre varias técnicas de control y también usado diferentes modelos matemáticos del sistema [13-15]. Entre los controladores más usados para resolver los problemas de seguimiento de trayectoria y de regulación están: el control por linealización entrada-salida [16], el control por visión [17], el control adaptivo [18], el control por modos deslizantes [19], el control óptimo *backstepping* [20], el control robusto no lineal adaptivo [21], entre otros.

Este artículo propone un controlador robusto para afrontar el problema de regulación del subsistema de orientación de un quadrotor. El problema se divide en tres etapas: en la primera, se obtienen los modelos matemáticos, cinemático y dinámico. En la segunda etapa se presenta el diseño y la implementación del controlador robusto no lineal H_{∞} que compensa las fuentes de incertidumbre en el modelo debido a dinámicas no modeladas, errores en la estimación de parámetros, perturbaciones exógenas y ruido. En la tercera etapa se realizan las pruebas de funcionamiento y el análisis de desempeño del controlador en las plataformas de simulación y experimental, usando el ISE como criterio de desempeño y obteniéndose buenos resultados en comparación con un sistema de control clásico PID.

Este documento se organiza como sigue: La sección II presenta el modelado matemático del sistema considerando dinámicas no lineales traslacional y rotacional. La sección III muestra el procedimiento para el diseño del controlador robusto no lineal H_{∞} del sistema de orientación de la aeronave. La sección IV presenta los detalles de la implementación del controlador, tanto en la plataforma de simulación como en la plataforma experimental. La sección V presenta las conclusiones del trabajo.

II. MODELADO MATEMÁTICO DEL SISTEMA

A. Consideraciones del sistema

Un vehículo aéreo no tripulado (UAV por sus siglas en inglés) posee la configuración de cuatro motores coplanarios, como se muestra en la Fig. 1. La variación controlada de las velocidades en los motores permite el movimiento del quadrotor. El movimiento del sistema hacia adelante (pitch) se logra disminuyendo y aumentando las velocidades de los motores delantero (F1) y trasero (F3) respectivamente. Un desplazamiento lateral (roll) demanda el mismo procedimiento

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