A Review of UAVs Topologies and Control Techniques

Autor/Expositor :

M.Sc. Enrique Gabriel Paiva Galeano (enpaiva93@gmail.com)

Co-Autor:

Dr. Jorge Esteban Rodas Benítez, Dr. Yassine Kali, Fernando Lesme,
Jose Luis Lesme, Dr. José Rodríguez-Piñeiro

Universidad Católica de Caacupé

IEEE ICA-ACCA 2021

CONTENTS

CONTENTS

Introduction

Technology photo created by wirestock - www.freepik.es

An unmanned aerial vehicle (UAV) is an unmanned, reusable aircraft capable of autonomously maintaining a controlled and sustained level of flight.

USES FOR MILITARY PURPOSES

Fig. 1. First registered use of UAV, 1849. [1]

Fig. 2. UAV used in Battle of Neuve Chapelle, 1915. [2]

Introduction

USES FOR MILITARY PURPOSES

Fig. 3. UAV RQ-2 Pionner, 1986. [3]

Fig. 4. UAV MQ-1 Predator, 2002. [4]

USES FOR CIVILIAN PURPOSES

(a) (b)

Fig. 5. Current UAVs for non-military use. (a) Amazon Prime Air, (b) Phantom 4 Pro. [5]

CONTENTS

Classification of UAVs

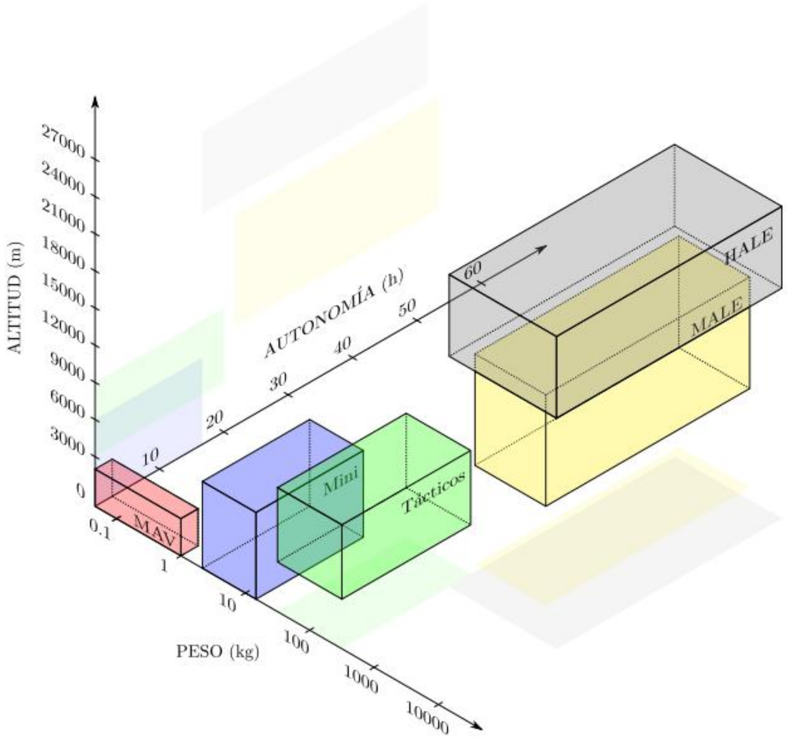


Fig. 6. Classification of UAVs according to weight, altitude and flight autonomy. [5]

When referring to classes of UAVs, there are sets of various nomenclatures used depending on the industry employing these aircraft. The various nomenclatures are based on a variety of parameters, such as mass, UAV configuration, designed application, level of autonomy, type of operation or military employment.

For this classification, five categories of current UAVs were defined based on [8]. The categories are: Micro (MAV), Mini, Tactical, Medium Altitude and High Altitude. Medium and high altitude UAVs are also known as Medium Altitude Long Endurance (MALE) or High Altitude Long Endurance (HALE) UAVs, indicating their ability to stay aloft for long periods of time.

Classification of UAVs

Multirotors

Fixed Wing

Hybrids

Classification of UAVs

Multirotors

Multirotor UAVs: they have several rotors that support the UAV by means of the thrust generated by the propellers. Depending on the number of propellers they can be: trirotor (with three rotors), quadrotor (with four rotors), hexarotor (six rotors) and octarotor (with eight rotors). The advantages and disadvantages are listed below [10].

- Advantages

⋆ Better maneuverability
⋆ Compact
⋆ Easy to use
⋆ Higher load capacity

- Disadvantages.

⋆ Short flight ranges
⋆ Difficult to recover in case of engine failure

Classification of UAVs

Fixed Wing

Fixed-wing UAVs: which have only rotors for propulsion and are kept in the air due to the lift of the wings. The advantages and disadvantages are listed below [10].

- Advantages.

⋆ Wide flight range
⋆ Recovery in case of engine failure
⋆ Linear flight advantages

- Disadvantages

⋆ Landing and take-off in large areas
⋆ Difficulty in maneuvering
⋆ Less compact

Classification of UAVs

Hybrids

Hybrid UAVs: is a combination of fixed wing and multirotor configurations, thus inheriting the advantages of both technologies. However, the control of this UAV is very complex. These UAVs are subclassified into:

- Hybrid tilt-wing UAVs: in the transition from one configuration to another, the platform remains fixed while the wings are folded down with the rotors.

- Hybrid tilt-rotor UAVs: in the transition from one configuration to the other, the platform and wings remain fixed while the rotors are folded down.

- Hybrid tilting platform UAVs: in the transition from one configuration to the other, the platform together with the rotors and wings are folded down.

Classification of UAVs

Fig. 7. Example of recreational UAVs.

Classification of UAVs

Fig. 8. Example of professional UAVs.

Classification of UAVs

Fig. 9. Example of a research UAV.

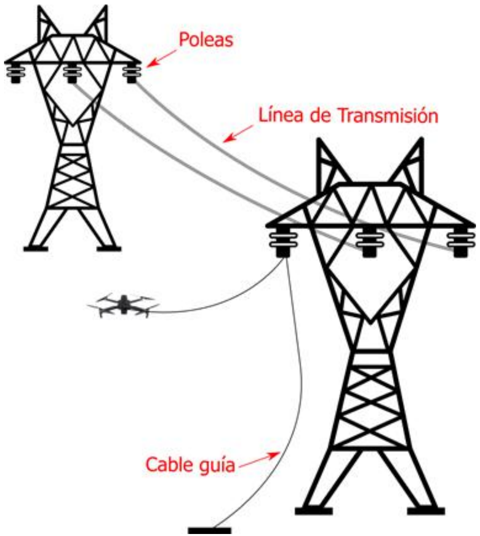
Classification of UAVs

Security and Surveillance

Freight Transportation

Fig. 10. Example of innovative UAVs.

Classification of UAVs



Laying of Guide Lines in High Voltage Towers

Power Generation - AWE (Airborne Wind Energy)

Fig. 11. Example of UAVs for innovative applications.

CONTENTS

Control in UAVs

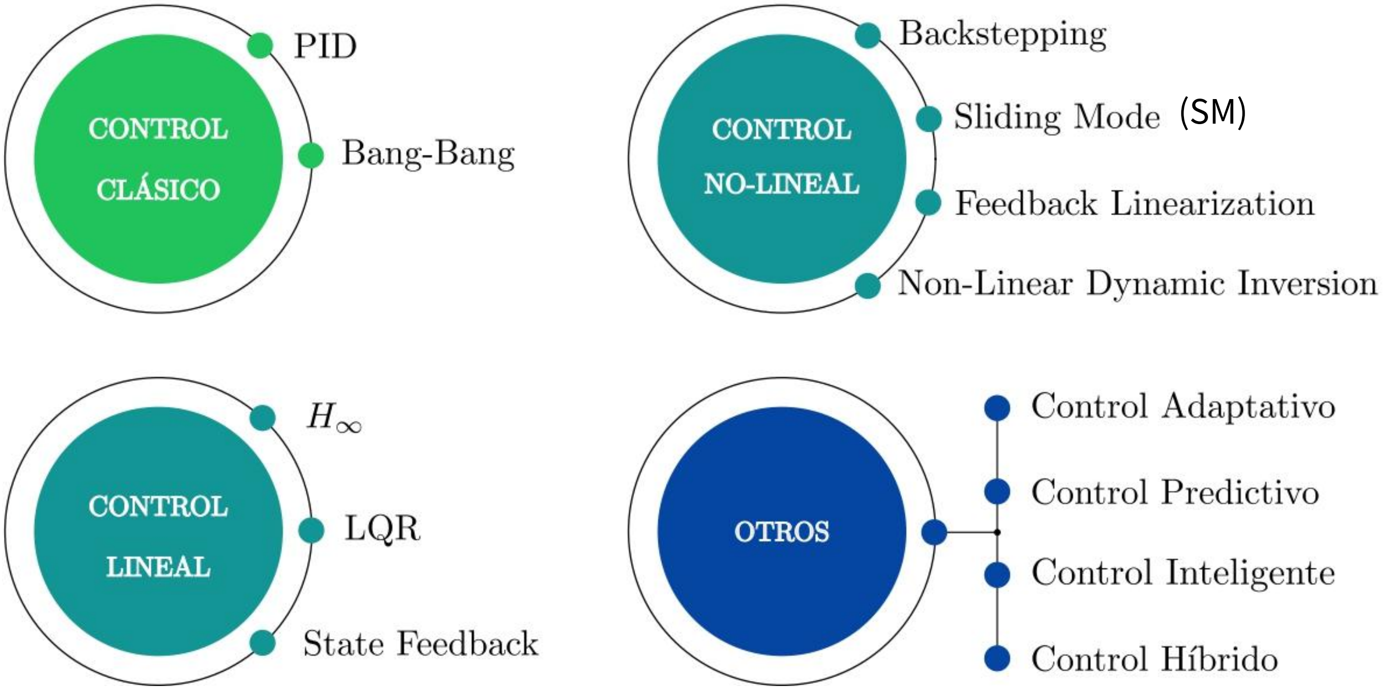


Fig. 12. Classification of controllers

Control in UAVs

<u>Proportional-Integral-Derivative (classical control):</u> is one of the most popular and widely used controllers in UAV due to its simplicity. PID controllers are considered as a classical approach in control theory.

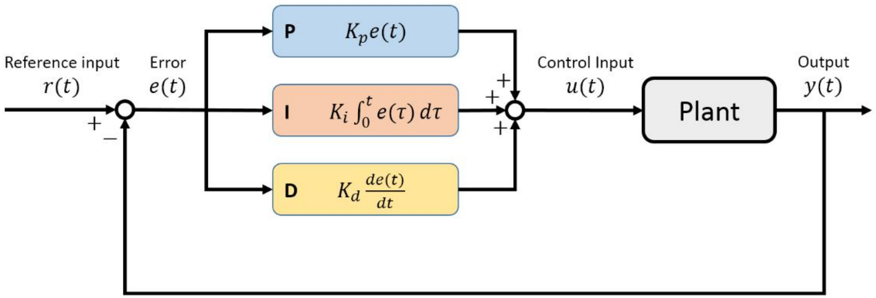


Fig. 13. PID controller block diagram. [16]

Use cases

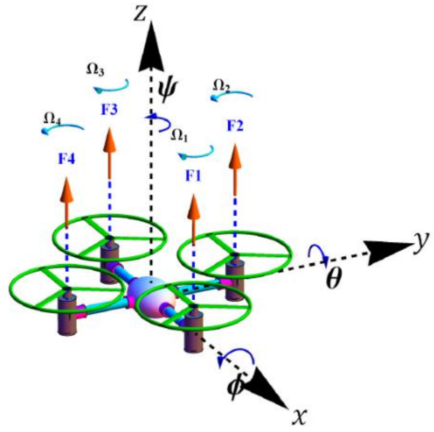
ARDUPILOT

PX4 autopilot

Control in UAVs

Linear Quadratic Regulator (linear control): Known by its acronym LQR, it is an optimal control method (like the H∞ controller [19]) with which the stability of a closed-loop system is ensured through feedback gains. This method seeks to minimize a cost function containing the states (x(t) ∈ Rn where n are the number of states) and control inputs (u(t) ∈ Rm where m are the number of inputs) of the system to be controlled, and is given by the following expression:

$J = \int_0^{\infty} [\, x(t)^T \, \mathrm{Q} \, x(t) + u(t)^T \, \mathrm{R} \, u(t) \,] \, \mathrm{d}t;$ where Q and R are matrices corresponding to the controller gains [20].



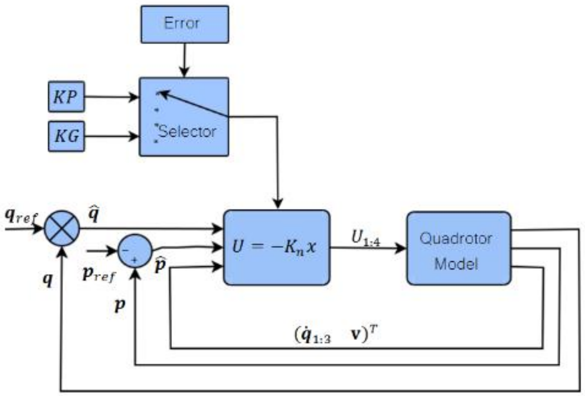
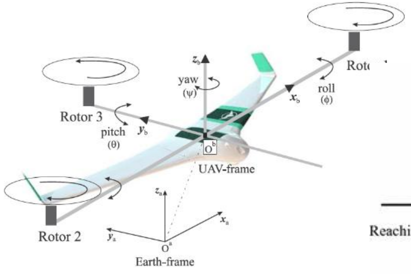


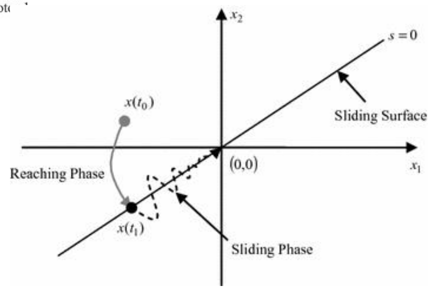
Fig. 14. LQR control scheme and tracking using quaternions. [20]

Control in UAVs

Sliding Mode Control (Non-linear Control): Commonly known as Sliding Mode (SM), it is a famous nonlinear technique robust to a large class of uncertainties and with convergence rates to the desired value (or reference) in finite time. This method uses discontinuous input signals that make changes to force the system states to converge in finite time to the so-called sliding surface and then to move across the sliding surface to the equilibrium point.

However, its application in real time is still restricted by the problem of the phenomenon known as Chattering. This problem is considered the major disadvantage of the SM controller, as it can lead to very poor performance and wear of the mechanical parts of the system. [29]





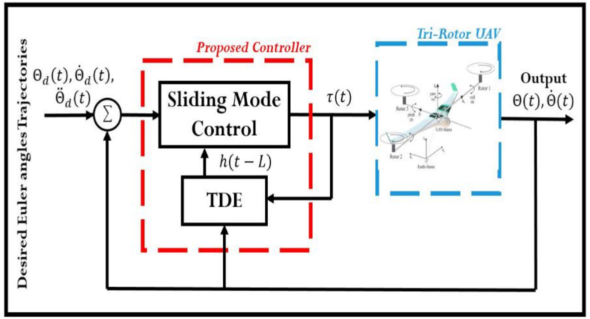
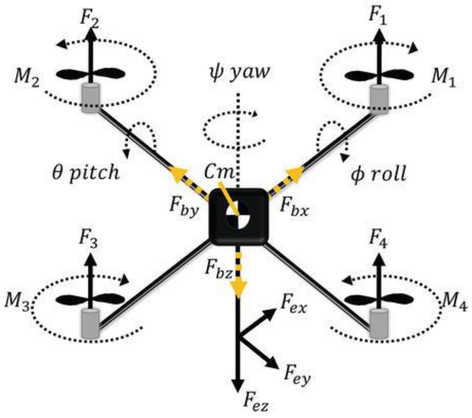


Fig. 15. SM control. [29]

Control in UAVs

Adaptive Control (other controllers): Adaptive control is a method that allows adapting the control from variable parameters, or that are initially unknown. Unlike non-adaptive controls, which maintain fixed control parameters throughout the operation. This method focuses on control changes, adjusting the different parameters according to variations in the platform and the environment [21].



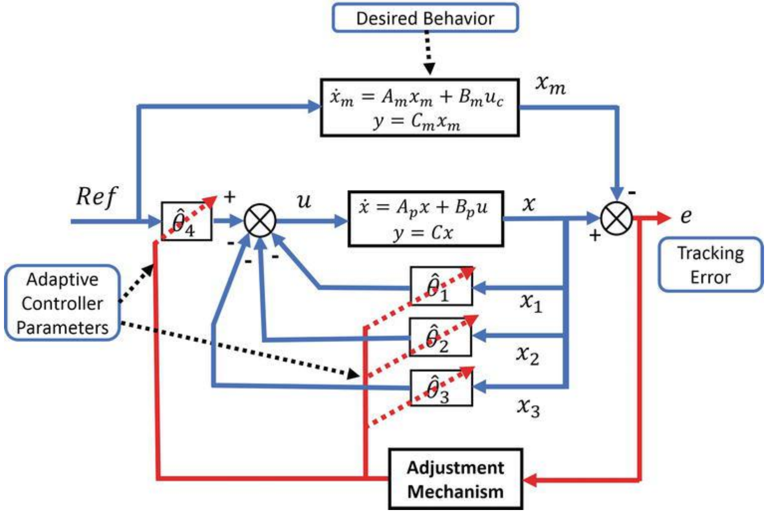


Fig. 16. Direct model reference adaptive control (MRAC). [37]

Control in UAVs

Like this, intelligent plant self-identification algorithms can be added, being intelligent controllers [22], [23] or minimizing an arbitrary cost function based on future predictions such as predictive control [24].

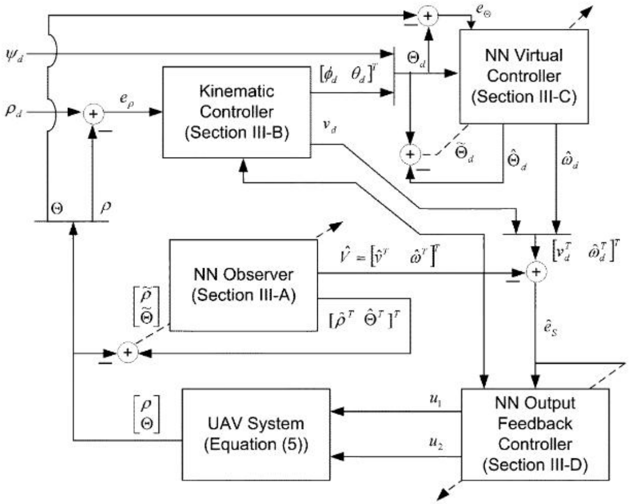


Fig. 17. Neural network control scheme. [22]

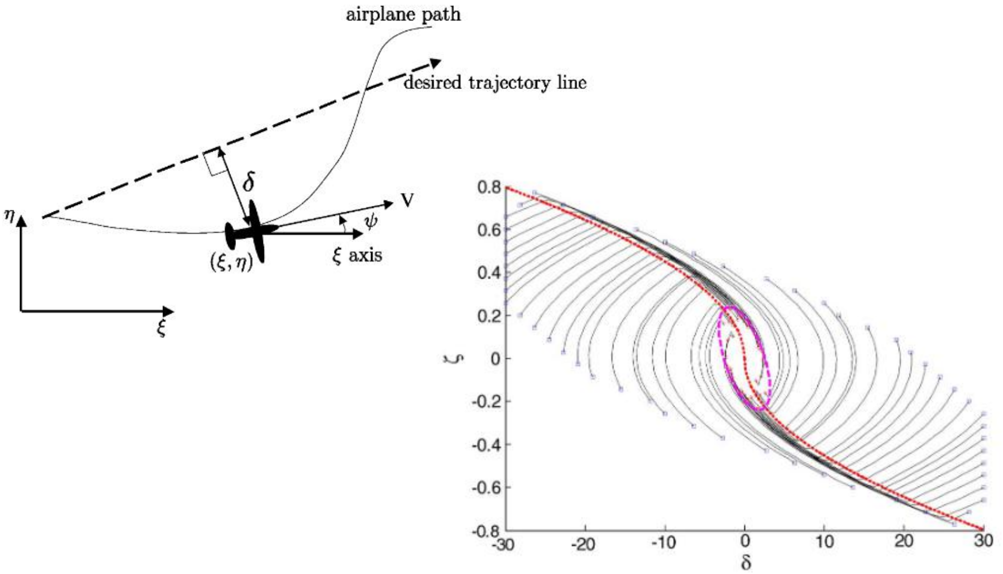


Fig. 18. Predictive control scheme for line tracking in fixed-wing UAVs. [24]

CONTENTS

Conclusions

In this article, the state of the art of UAVs was presented from a historical perspective. In addition, a classification of UAVs according to different parameters was proposed, mentioning the main advantages and disadvantages of each one. Likewise, this article has addressed the control schemes applied to UAVs, starting from the classical control to the newest ones based on nonlinear controllers.

References

[1] V. Prisacariu et al., “The history and the evolution of uavs from the beginning till the 70s,” Journal of Defense Resources Management (JoDRM), vol. 8, no. 1, pp. 181—189, 2017.
[2] J. Black, Air Power: A Global History. Rowman & Littlefield, 2016.
[3] L. R. Newcome, Unmanned aviation: a brief history of unmanned aerial vehicles. American Institute of Aeronautics and Astronautics, 2004.
[4] S. O’Donnell, A Short History of Unmanned Aerial Vehicles. 2019.
[5] R. O. Hundley and E. C. Gritton, “Future technology-driven revolutions in military operations,” RAND Corporation, Document No. DB-110-ARPA, 1994.
[6] General Atomics MQ-1 Predator.
[7] M. Miller, The internet of things: How smart TVs, smart cars, smart homes, and smart cities are changing the world. Pearson Education, 2015.
[8] R. Weibel and R. Hansman, “Safety considerations for operation of unmanned aerial vehicles in the national airspace system,” 11 2006.
[9] K. Munson and M. Streetly, “Jane’s unmanned aerial vehicles and targets,” 2006.
[10] J. Rejón, Multi-rotor o Ala fija. 2018.
[11] E. Paiva and M. Llano, “Diseño e implementación de un sistema de transición en vuelo y elaboración de un modelo matemático no lineal para vehículos aereos no tripulados híbridos. prototipo version 2.0,” tesis de grado, Facultad de Ingenier´ıa de la Universidad Nacional deASuncion, Mayo 2018.
[12] A. Kharsansky, “Diseño e implementación de un sistema embebido de control de actitud para aeronaves no tripuladas,” tesis de grado, Facultad de Ingeniería de la Universidad de Buenos Aires, Mayo 2013.
[13] H. Obanawa and H. Shibata, “Applications of uav remote sensing to topographic and vegetation surveys,” in Unmanned Aerial Vehicle: Applications in Agriculture and Environment, pp. 131—142, Springer, 2020.
[14] T. Alladi, V. Chamola, N. Sahu, and M. Guizani, “Applications of blockchain in unmanned aerial vehicles: A review,” Vehicular Commu_x0002_nications, p. 100249, 2020.
[15] D. Giordan, M. S. Adams, I. Aicardi, M. Alicandro, P. Allasia, M. Baldo, P. De Berardinis, D. Dominici, D. Godone, P. Hobbs, et al., “The use of unmanned aerial vehicles (uav) for engineering geology applications,” Bull. Eng. Geol. Environ, 2020.
[16] J. Kim, S. A. Gadsden, and S. A. Wilkerson, “A comprehensive survey of control strategies for autonomous quadrotors,” Canadian Journal of Electrical and Computer Engineering, vol. 43, no. 1, pp. 3—16, 2019.
[17] S. Khatoon, M. Shahid, H. Chaudhary, et al., “Dynamic modeling and stabilization of quadrotor using pid controller,” in 2014 International Conference on Advances in Computing, Communications and Informat_x0002_ics (ICACCI), pp. 746—750, IEEE, 2014.
[18] A. L. Salih, M. Moghavvemi, H. A. Mohamed, and K. S. Gaeid, “Modelling and pid controller design for a quadrotor unmanned air vehicle,” in 2010 IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR), vol. 1, pp. 1—5, IEEE, 2010.
[19] K. Masuda and K. Uchiyama, “Robust control design for quad tilt-wing uav,” Aerospace, vol. 5, no. 1, p. 17, 2018.
[20] E. Reyes-Valeria, R. Enriquez-Caldera, S. Camacho-Lara, and J. Guichard, “Lqr control for a quadrotor using unit quaternions: Modeling and simulation,” in CONIELECOMP 2013, 23rd International Conference on Electronics, Communications and Computing, pp. 172—178, IEEE, 2013.

References

[21] A. Ataka, H. Tnunay, R. Inovan, M. Abdurrohman, H. Preastianto, A. I. Cahyadi, and Y. Yamamoto, “Controllability and observability analysis of the gain scheduling based linearization for uav quadrotor,”
in 2013 International conference on robotics, biomimetics, intelligent computational systems, pp. 212—218, IEEE, 2013.
[22] T. Dierks and S. Jagannathan, “Output feedback control of a quadrotor uav using neural networks,” IEEE transactions on neural networks, vol. 21, no. 1, pp. 50—66, 2009.
[23] N. Nafia, A. El Kari, H. Ayad, and M. Mjahed, “Robust full tracking control design of disturbed quadrotor uavs with unknown dynamics,” Aerospace, vol. 5, no. 4, p. 115, 2018.
[24] Y. Kang and J. K. Hedrick, “Linear tracking for a fixed-wing uav using nonlinear model predictive control,” IEEE Transactions on Control Systems Technology, vol. 17, no. 5, pp. 1202—1210, 2009.
[25] Y. Kali, J. Rodas, M. Ayala, M. Saad, R. Gregor, K. Benjelloun, J. Doval_x0002_Gandoy, and G. Goodwin, “Discrete-time sliding mode with time delay estimation of a six-phase induction motor drive,” in IECON 2018 - 44th Annual Conference of the IEEE Industrial Electronics Society, pp. 5807—5812, Oct 2018.
[26] Y. Kali, M. Ayala, J. Rodas, M. Saad, J. Doval-Gandoy, R. Gregor, and K. Benjelloun, “Current control of a six-phase induction machine drive based on discrete-time sliding mode with time delay estimation,” Energies, vol. 12, no. 1, 2019.
[27] Y. Feng, X. Yu, and Z. Man, “Non-singular terminal sliding mode control of rigid manipulators,” Automatica, vol. 38, no. 12, pp. 2159 — 2167, 2002.
[28] Y. Kali, M. Saad, K. Benjelloun, and M. Benbrahim, “Sliding mode with time delay control for mimo nonlinear systems with unknown dynamics,” in 2015 International Workshop on Recent Advances in Sliding Modes (RASM), pp. 1—6, April 2015.
[29] K. Runcharoon and V. Srichatrapimuk, “Sliding mode control of quadrotor,” in TAEECE, International Conference on Technological Advances in Electrical, Electronics and Computer Engineering, pp. 552—557, May 2013.
[30] M. Tseng and M. Chen, “Chattering reduction of sliding mode control by low-pass filtering the control signal,” Asian Journal of Control, vol. 12, no. 3, pp. 392—398, 2010.
[31] D. Lee, H. Jin Kim, and S. Sastry, “Feedback linearization vs. adaptive sliding mode control for a quadrotor helicopter,” International Journal of Control, Automation and Systems, vol. 7, pp. 419—428, Jun 2009.
[32] Y. Kali, J. Rodas, R. Gregor, M. Saad, and K. Benjelloun, “Attitude tracking of a tri-rotor uav based on robust sliding mode with time delay estimation,” in 2018 International Conference on Unmanned Aircraft Systems (ICUAS), pp. 346—351, June 2018.
[33] A. Levant, “Higher-order sliding modes, differentiation and output feedback control,” International Journal of Control, vol. 76, no. 9-10, pp. 924—941, 2003.
[34] Y. Kali, M. Saad, and K. Benjelloun, “Non-singular terminal second order sliding mode with time delay estimation for uncertain robot manipulators,” in ICINCO, International Conference on Informatics in Control, Automation and Robotics, pp. 226—232, 2017.
[35] A. Benallegue, A. Mokhtari, and L. Fridman, “High-order sliding-mode observer for a quadrotor UAV,” International Journal of Robust and Nonlinear Control, vol. 18, no. 4-5, pp. 427—440, 2008.
[36] Y. Kali, M. Saad, K. Benjelloun, and C. Khairallah, “Super-twisting algorithm with time delay estimation for uncertain robot manipulators,” Nonlinear Dynamics, vol. 93, pp. 557—569, Jul 2018
[37] Pérez, R., Galvan, G., Vázquez, A., Melo, S. and Alabazares, D., . “Attitude Control of a Quadcopter Using Adaptive Control Technique.” Adaptive Robust Control Systems,. 2018.

Thanks!