Geometric Tracking Control of an Unmanned Aerial Vehicle based on the Moving Mass Concept on SE(3)

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***Abstract*— This paper is focused on presenting the concept of geometric tracking control for a specific unmanned aerial vehicle (UAV) based on the moving mass concept. It has the ability to exploit its dynamic center of mass as a means of stabilization and control. A mathematical model of such system will be given as grounds for developing the nonlinear geometric tracking controller on the special Euclidean group SE(3). It will be shown that the chosen control terms have desirable properties. Finally, Gazebo simulation results for a selected trajectory tracking problem will be presented using a model of an aerial robot consisting of two moving masses distributed in a standard plus configuration.**

I. introduction

TODO: Introduction

II. Mathematical model

TODO: Mathematical model...

III. Mid-ranging control concept

TODO: Control...

IV. Simulation

TODO: Simulation...

V. Experiments

Experiments...

VI. Conclusion

Conclusions

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References

[1] K. Alexis, G. Darivianakis, M. Burri, and R. Siegwart, "Aerial robotic contact-based inspection: planning and control," *Autonomous Robots*, vol. 40, no. 4, pp. 631–655, 2016.

[2] A. E. Jimenez-Cano, J. Martin, G. Heredia, A. Ollero, and R. Cano, "Control of an aerial robot with multi-link arm for assembly tasks," in *Proceedings - IEEE International Conference on Robotics and Automation*, pp. 4916–4921, IEEE, 5 2013.

[3] H. Tsukagoshi, M. Watanabe, T. Hamada, D. Ashlih, and R. Iizuka, "Aerial manipulator with perching and door-opening capability," in *2015 IEEE International Conference on Robotics and Automation (ICRA)*, pp. 4663–4668, 2015.

[4] C. Korpela, M. Orsag, and P. Oh, "Towards valve turning using a dual-arm aerial manipulator," in *Intelligent Robots and Systems (IROS 2014), 2014 IEEE/RSJ International Conference on*, pp. 3411–3416, 2014.

[5] P. E. Pounds, D. R. Bersak, and A. M. Dollar, "Stability of small-scale UAV helicopters and quadrotors with added payload mass under PID control," *Autonomous Robots*, vol. 33, no. 1-2, pp. 129–142, 2012.

[6] I. Palunko and R. Fierro, "Adaptive control of a quadrotor with dynamic changes in the center of gravity," in *Proceedings 18th IFAC World Congress*, vol. 18, pp. 2626–2631, 2011.

[7] C. Korpela, M. Orsag, T. Danko, B. Kobe, C. McNeil, R. Pisch, and P. Oh, "Flight stability in aerial redundant manipulators," in *2012 IEEE International Conference on Robotics and Automation*, pp. 3529–3530, IEEE, 5 2012.

[8] "Morus project." `http://www.fer.unizg.hr/morus`. Accessed: 2017-09-08.

[9] T. Haus, M. Orsag, and S. Bogdan, "Mathematical Modelling and Control of an Unmanned Aerial Vehicle with Moving Mass Control Concept," *Journal of Intelligent and Robotic Systems: Theory and Applications*, 2017.

[10] C. Bermes, S. Leutenegger, S. Bouabdallah, D. Schafroth, and R. Siegwart, "New design of the steering mechanism for a mini coaxial helicopter," in *Intelligent Robots and Systems, 2008. IROS 2008. IEEE/RSJ International Conference on*, pp. 1236–1241, IEEE, 2008.

[11] B. J. Allison and A. J. Isaksson, "Design and Performance of Mid-Ranging Controllers," *IFAC Proceedings Volumes*, vol. 30, no. 9, pp. 523–528, 1997.

[12] B. J. Allison and S. Ogawa, "Design and tuning of valve position controllers with industrial applications," *Transactions of the Institute of Measurement and Control*, vol. 25, no. 1, pp. 3–16, 2003.

[13] O. Sornmo, B. Olofsson, A. Robertsson, and R. Johansson, "Adaptive internal model control for mid-ranging of closed-loop systems with internal saturation," *IEEE International Conference on Intelligent Robots and Systems*, pp. 4893–4899, 2013.

[14] Z. Ma, G. S. Hong, M. H. Ang, and A. N. Poo, "Mid-ranging control of a macro/mini manipulator," in *2015 IEEE International Conference on Advanced Intelligent Mechatronics (AIM)*, pp. 755–760, July 2015.

[15] T. Haus, A. Ivanovic, M. Car, M. Orsag, and S. Bogdan, "Mid-ranging control concept for a multirotor uav with moving masses," in *2018 26th Mediterranean Conference on Control and Automation (MED)*, June 2018.

[16] T. Haus, M. Orsag, and S. Bogdan, "A concept of a non-tilting multirotor-uav based on moving mass control," in

2017 International Conference on Unmanned Aircraft Systems (ICUAS), pp. 1618–1624, June 2017.

[17] F. Furrer, M. Burri, M. Achtelik, and R. Siegwart, *Robot Operating System (ROS): The Complete Reference (Volume 1)*, ch. RotorS—A Modular Gazebo MAV Simulator Framework, pp. 595–625. Cham: Springer International Publishing, 2016.

[18] J. Meyer, A. Sendobry, S. Kohlbrecher, U. Klingauf, and O. von Stryk, "Comprehensive simulation of quadrotor uavs using ros and gazebo," in *3rd Int. Conf. on Simulation, Modeling and Programming for Autonomous Robots (SIMPAR)*, p. to appear, 2012.

[19] "Laboratory for robotics and intelligent control systems youtube channel." `https://goo.gl/1PWUJ2`.

[20] "mmuav gazebo." `https://github.com/larics/mmuav_gazebo`, 2018.

[21] "px4-firmware." `https://github.com/larics/px4-firmware`, 2018.