succeeded in maintaining the robot's attitude and recovering from a stall.

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Number JP21K03965 and TMU local 5G research support.

REFERENCES

[1] J. Zhang, C. Dong, and A. Song, "Jumping aided takeoff: Conceptual design of a bio-inspired jumping-flapping multi-modal locomotion robot," in *2017 IEEE International Conference on Robotics and Biomimetics (ROBIO)*, 2017, pp. 32–37.

[2] S. Yang, Y. Shen, B. Li, Y. Li, and J. Zhang, "Modeling and Simulation of a Flapping-Wing Robot with Active Tails for Balancing Control during Wheeled Running," in *2018 IEEE International Conference on Mechatronics and Automation (ICMA)*, 2018, pp. 1806–1811. doi: 10.1109/ICMA.2018.8484330.

[3] M. L. Afakh, T. Sato, H. Sato, and N. Takesue, "Development of Flapping Robot with Self-Takeoff from The Ground Capability," in *2021 IEEE International Conference on Robotics and Automation (ICRA)*, 2021, pp. 321–327.

[4] A. A. Paranjape, S.-J. Chung, and J. Kim, "Novel Dihedral-Based Control of Flapping-Wing Aircraft With Application to Perching," *IEEE Transactions on Robotics*, vol. 29, no. 5, pp. 1071–1084, Oct. 2013, doi: 10.1109/TRO.2013.2268947.

[5] S. R. Nekoo, D. Feliu-Talegon, J. A. Acosta, and A. Ollero, "A 79.7g Manipulator Prototype for E-Flap Robot: A Plucking-Leaf Application," *IEEE Access*, vol. 10, pp. 65300–65308, Aug. 2022, doi: 10.1109/ACCESS.2022.3184110.

[6] D. Bie, D. Li, J. Xiang, H. Li, Z. Kan, and Y. Sun, "Design, aerodynamic analysis and test flight of a bat-inspired tailless flapping wing unmanned aerial vehicle," *Aerosp Sci Technol*, vol. 112, p. 106557, 2021, doi: https://doi.org/10.1016/j.ast.2021.106557.

[7] G. Arranz, O. Flores, and M. García-Villalba, "Three-dimensional effects on the aerodynamic performance of flapping wings in tandem configuration," *J Fluids Struct*, vol. 94, p. 102893, 2020, doi: https://doi.org/10.1016/j.jfluidstructs.2020.102893.

[8] R. Addo-Akoto, J.-S. Han, and J.-H. Han, "Roles of wing flexibility and kinematics in flapping wing aerodynamics," *J Fluids Struct*, vol. 104, p. 103317, 2021, doi: https://doi.org/10.1016/j.jfluidstructs.2021.103317.

[9] S.-H. Yoon, H. Cho, J. Lee, C. Kim, and S.-J. Shin, "Effects of camber angle on aerodynamic performance of flapping-wing micro air vehicle," *J Fluids Struct*, vol. 97, p. 103101, 2020, doi: https://doi.org/10.1016/j.jfluidstructs.2020.103101.

[10] K. Sanuki and T. Fujikawa, "Motion Analysis of Butterfly-Style Flapping Robot Using CFD Based on 3D-CAD Model and Experimental Flight Data," *Journal of Robotics and Mechatronics*, vol. 33, no. 2, pp. 216–222, 2021, doi: 10.20965/jrm.2021.p0216.

[11] C. Ding, "Dynamic performances of a bird-like flapping wing robot under randomly uncertain disturbances," *PLoS One*, vol. 15, no. 5, pp. e0232202-, May 2020, [Online].

[12] F. Fei, Z. Tu, Y. Yang, J. Zhang, and X. Deng, "Flappy Hummingbird: An Open Source Dynamic Simulation of Flapping Wing Robots and Animals," in *2019 International Conference on Robotics and Automation (ICRA)*, 2019, pp. 9223–9229. doi: 10.1109/ICRA.2019.8794089.

[13] Z. Wang and T. Hong, "Reinforcement learning for building controls: The opportunities and challenges," *Appl Energy*, vol. 269, p. 115036, 2020, doi: https://doi.org/10.1016/j.apenergy.2020.115036.

[14] H. V. Phan and H. C. Park, "Insect-inspired, tailless, hover-capable flapping-wing robots: Recent progress, challenges, and future directions," *Progress in Aerospace Sciences*, vol. 111, p. 100573, 2019, doi: https://doi.org/10.1016/j.paerosci.2019.100573.

[15] Y. M. Chukewad, J. James, A. Singh and S. Fuller, "RoboFly: An Insect-Sized Robot With Simplified Fabrication That Is Capable of Flight, Ground, and Water Surface Locomotion," in *IEEE Transactions on Robotics*, vol. 37, no. 6, pp. 2025-2040, Dec. 2021.

[16] Z. Ren *et al.*, "A High-Lift Micro-Aerial-Robot Powered by Low-Voltage and Long-Endurance Dielectric Elastomer Actuators," *Advanced Materials*, vol. 34, no. 7, p. 2106757, Feb. 2022, doi: https://doi.org/10.1002/adma.202106757.

[17] Z. Tu, F. Fei, J. Zhang, and X. Deng, "An At-Scale Tailless Flapping-Wing Hummingbird Robot. I. Design, Optimization, and Experimental Validation," *IEEE Transactions on Robotics*, vol. 36, no. 5, pp. 1511–1525, 2020, doi: 10.1109/TRO.2020.2993217.

[18] S. B. Fuller, "Four Wings: An Insect-Sized Aerial Robot With Steering Ability and Payload Capacity for Autonomy," *IEEE Robot Autom Lett*, vol. 4, no. 2, pp. 570–577, 2019.

[19] H.-W. Song, Y. Saffar Talori, and J.-S. Zhao, "Bionic Flapping Mechanism of the Wings of a Cursorial Dinosaur Robot for Estimating Its Lift and Thrust," *J Mech Robot*, vol. 13, pp. 1–10, Sep. 2020, doi: 10.1115/1.4048429.

[20] S. Zhong and W. Xu, "Power Modeling and Experiment Study of Large Flapping-Wing Flying Robot during Forward Flight," *Applied Sciences*, vol. 12, no. 6, 2022, doi: 10.3390/app12063176.

[21] R. Zufferey *et al.*, "Design of the High-Payload Flapping Wing Robot E-Flap," *IEEE Robot Autom Lett*, vol. 6, no. 2, pp. 3097–3104, 2021, doi: 10.1109/LRA.2021.3061373.

[22] W. Xu, E. Pan, J. Liu, Y. Li, and H. Yuan, "Flight control of a large-scale flapping-wing flying robotic bird: System development and flight experiment," *Chinese Journal of Aeronautics*, vol. 35, no. 2, pp. 235–249, 2022, doi: https://doi.org/10.1016/j.cja.2021.03.009.

[23] M. Sharifzadeh and D. M. Aukes, "Curvature-Induced Buckling for Flapping-Wing Vehicles," *IEEE/ASME Transactions on Mechatronics*, vol. 26, no. 1, pp. 503–514, 2021.

[24] X. Fan, K. Breuer, and H. Vejdani, "Wing Fold and Twist Greatly Improves Flight Efficiency for Bat-Scale Flapping Wing Robots," in *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Sep. 2021, pp. 7391–7397.

[25] W. Shyy, H. Aono, C. Kang, and H. Liu, *An Introduction to Flapping Wing Aerodynamics*. Cambridge: Cambridge University Press, 2013. doi: DOI: 10.1017/CBO9781139583916.

[26] Jr. John D. Anderson, *Fundamentals of aerodynamics*, 5th ed. McGraw-Hill, 2011.

[27] L.-J. Yang and B. Esakki, *Flapping Wing Vehicles: Numerical and Experimental Approach*. 2021. doi: 10.1201/9780429280436.

[28] V. Perez-Sanchez, A. E. Gomez-Tamm, E. Savastano, B. C. Arrue, and A. Ollero, "Bio-Inspired Morphing Tail for Flapping-Wings Aerial Robots Using Macro Fiber Composites," *Applied Sciences*, vol. 11, no. 7, 2021, doi: 10.3390/app11072930.

[29] M. M. Guzmán *et al.*, "Design and comparison of tails for bird-scale flapping-wing robots," in *2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Sep. 2021, pp. 6358–6365. doi: 10.1109/IROS51168.2021.9635990.

[30] P. Estefo, J. Simmonds, R. Robbes, and J. Fabry, "The Robot Operating System: Package reuse and community dynamics," *Journal of Systems and Software*, vol. 151, pp. 226–242, 2019, doi: https://doi.org/10.1016/j.jss.2019.02.024.

[31] X. Lang, B. Song, W. Yang, and W. Song, "Aerodynamic performance of owl-like airfoil undergoing bio-inspired flapping kinematics," *Chinese Journal of Aeronautics*, vol. 34, no. 5, pp. 239–252, 2021, doi: https://doi.org/10.1016/j.cja.2020.10.017.

[32] H. Sato, M. L. Afakh, and N. Takesue, "Development of Flapping-wing Robot with Independently Controllable Wings," *The Abstracts of the international conference on advanced mechatronics : toward evolutionary fusion of IT and mechatronics : ICAM*, vol. 2021.7, pp. GS6-2-, 2021.

[33] I. Diez-de-los-Rios, A. Suarez, E. Sanchez-Laulhe, I. Armengol, and A. Ollero, "Winged Aerial Robot: Modular Design Approach," in *2021 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR)*, 2021, pp. 190–195.

[34] [34] H. Huang, W. He, J. Wang, L. Zhang, and Q. Fu, "An All Servo-Driven Bird-Like Flapping-Wing Aerial Robot Capable of Autonomous Flight," *IEEE/ASME Transactions on Mechatronics*, pp. 1–11, 2022, doi: 10.1109/TMECH.2022.3182418.

[35] R. A. Paz, "The design of the PID controller," *Klipsch school of Electrical and Computer engineering*, vol. 8, pp. 1–23, 2001.