Solar-Powered, Long-Endurance UAV for Real-Time Onboard Data Processing

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ABSTRACT

In recent years, we have seen an uptrend in the popularity of unmanned aerial vehicles (UAVs) applying them in countless scenarios, ranging from agricultural observation to mobile base stations. The key aspects of the progress of UAVs are endurance and safety. For endurance, a solar-powered, highly efficient aircraft managing the distribution of its power resources to the different subsystems holds the potential for continuous flight during daylight hours. For safety, the operating of UAVs can be constrained to a designated area defined by a geo-fence.

A novel kinematic model for fixed-wing UAVs is presented, which can be used for geo-fencing algorithms. Additionally, a data-driven power model for propulsion power estimation based on aircraft state is discussed.

GEO-FENCING KINEMATIC MODEL

For geo-fencing applications on fixed-wing UAVs, a precise kinematic model is needed. The presented model is based on a constant roll-rate assumption. Representing the position of the aircraft in x and y directions on the complex plane as $c(t) = x(t) + \mathrm{i}y(t)$ allows the description of every point on the trajectory in the following way:

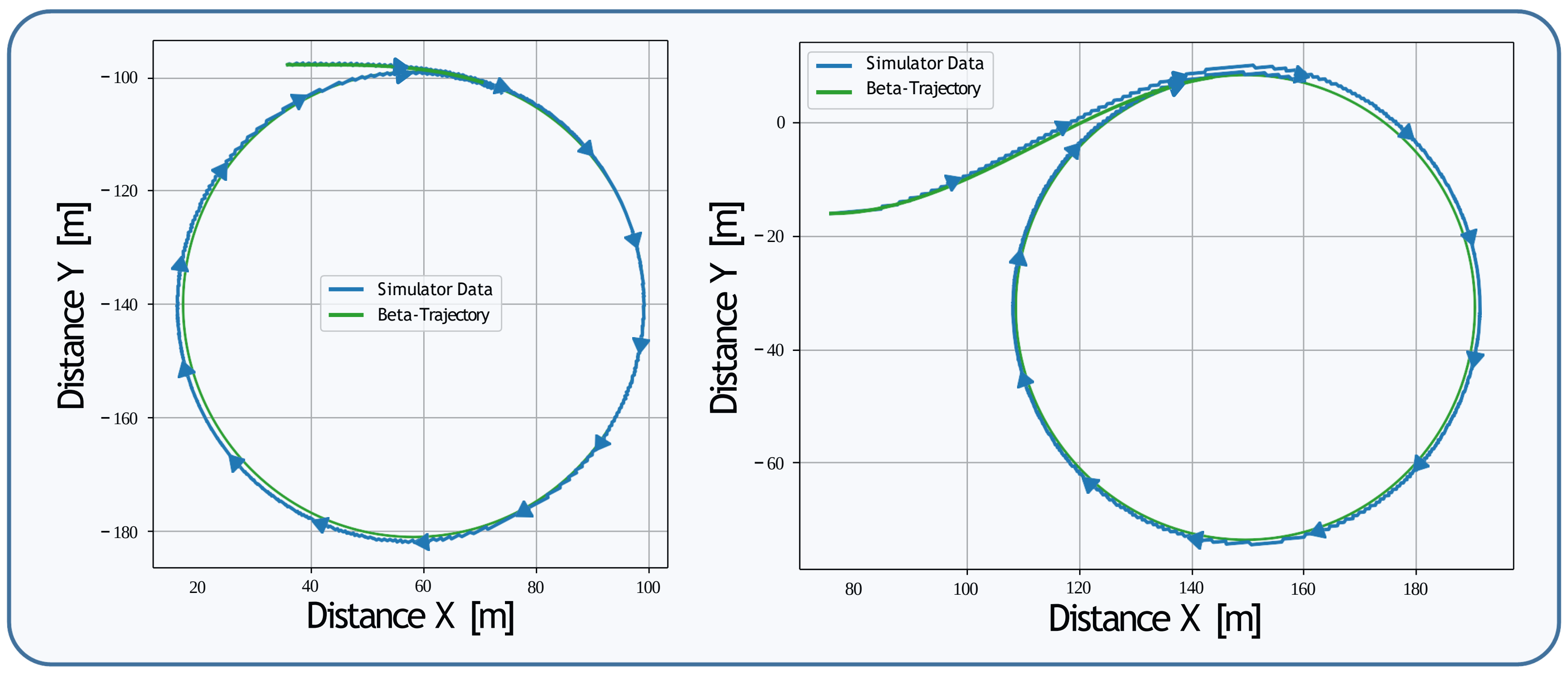
Constant Roll-Rate:
$$\phi(t) = rt + \phi_0$$

Beta-Curve:
$$\beta(\phi) = \operatorname{sign}(\phi)\frac{V}{2r}\left[B(1; a, b) - B(\cos^2\phi\,; a, b)\right]$$

Beta Incomplete Function:
$$B(x; a, b) = \int_0^x y^{a-1}(1-y)^{b-1}dy$$

Parameters:
$$a = \frac{1}{2} + \mathrm{i}\frac{g}{2Vr}\,, \qquad b = \frac{1}{2}$$

The full derivation of the Beta-Curve can be found in [1]. Using the uavEE Emulation Environment in [3], the predicted trajectory is compared to the flight path of an aircraft in a high-fidelity simulation. Two examples show the difference of the trajectory, given a different initial roll angle (0 degree and -45 degrees) rolling up to 45 degrees.



The simulation shows a high accuracy of the Beta-Trajectory as well as a significant dependency on the initial roll angle. Using the new kinematic model a geo-fencing algorithm is developed that estimates critical points on the trajectory, evaluates them, and if needed overrides the control of the aircraft.

DATA-DRIVEN POWER MODELING

The presented power model follows a holistic approach for fixed-wing electric UAV propulsion power consumption that encompasses both aircraft aerodynamics and propulsion models under realistic assumptions. The model estimates the power consumption at battery level based on aircraft state data. [2, 3]

Propulsion Power Modeling

$$P_{bat} = \frac{K_i}{\eta_m\eta_p}\frac{\cos^2\gamma}{v\cos^2\phi} + \frac{K_p}{\eta_m\eta_p}v^3 + \frac{m}{\eta_m\eta_p}(g\sin\gamma + a)v$$

g, m, K_i, K_p	gravity, mass, aerodyn. coefficients	v, a	velocity, acceleration
η_m, η_p	motor and propeller efficiency	γ, ϕ	climb and roll angle

Data-Driven Approach

Weights:
$$w = \left[\frac{K_i}{\eta_m\eta_p}, \frac{K_p}{\eta_m\eta_p}, \frac{m}{\eta_m\eta_p}\right]$$

Kernel Function:
$$\mathrm{f}(\gamma, \phi, v, a) = \left[\frac{\cos^2\gamma}{v\cos^2\phi}, v^3, (g\sin\gamma + a)v\right]$$

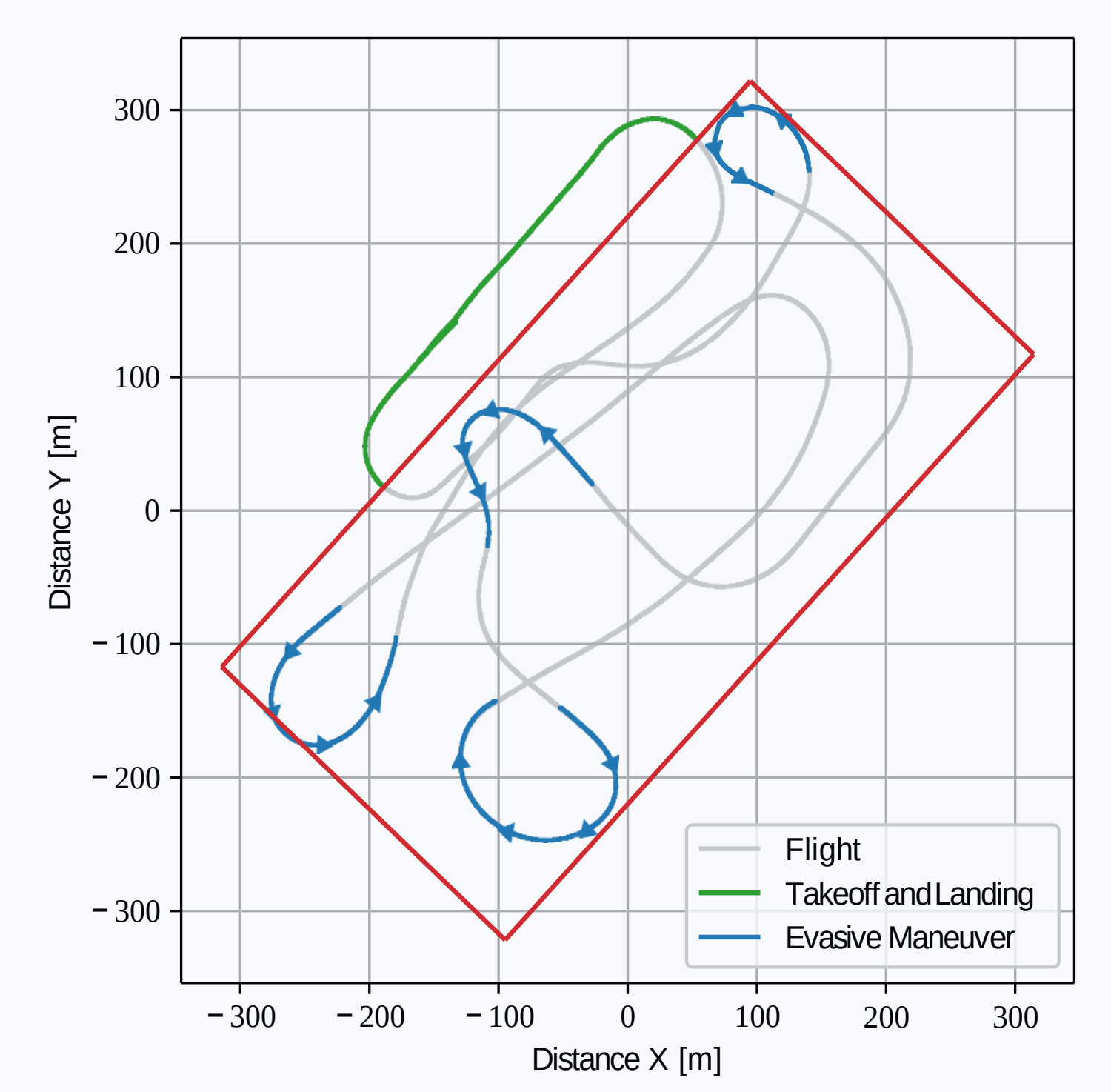
Linear Dependency:
$$P_{bat} = w\mathrm{f}(\gamma, \phi, v, a)^T$$

Using a data-driven approach, the aircraft parameters are estimated using linear regression with a non-linear modeled kernel function. This approach allows the power model to be used on different fixed-wing aircraft without expensive wind-tunnel testing.

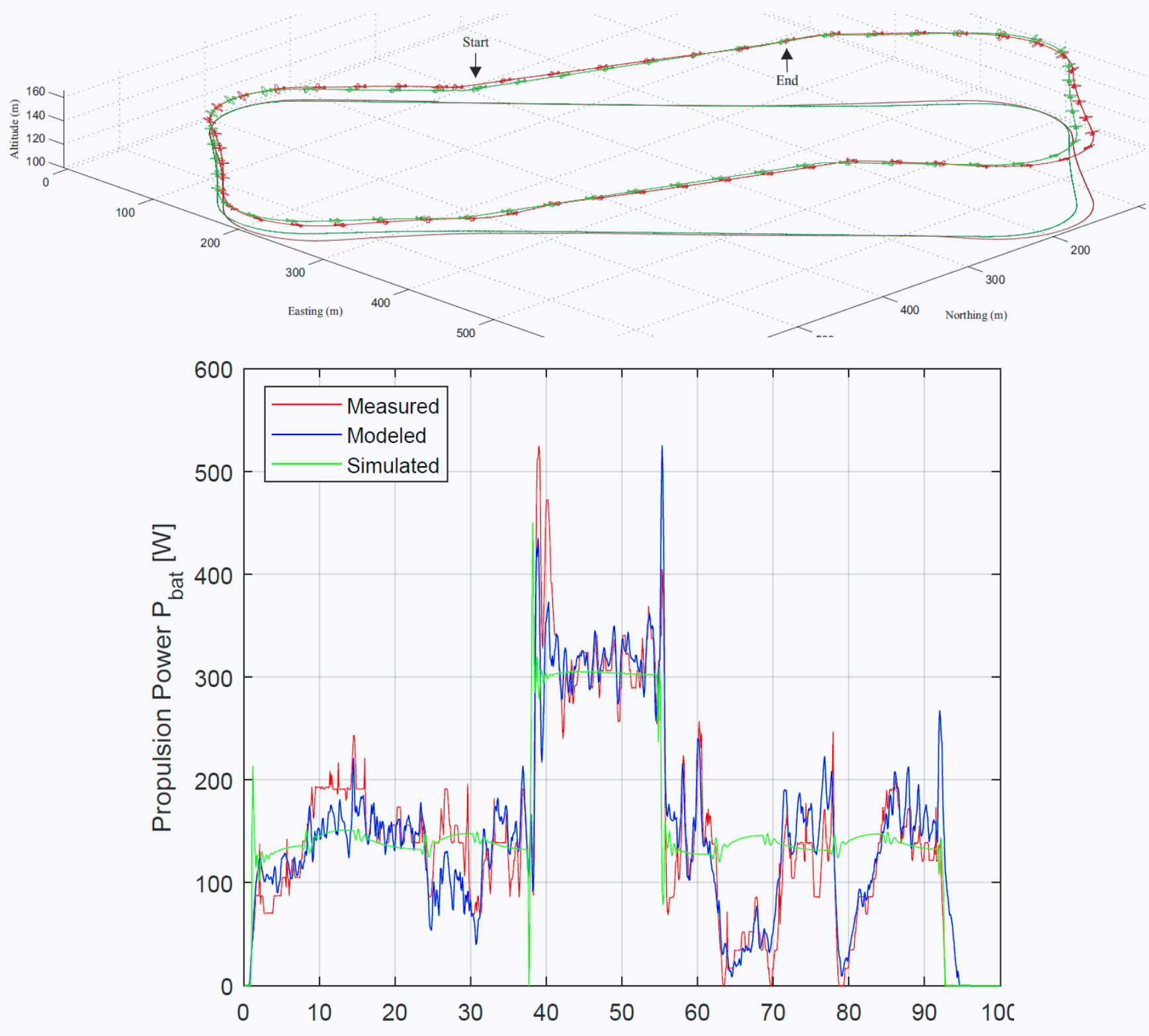
EVALUATION

The models were evaluated by means of flight testing as well as simulation. To test the geo-fencing algorithm, the autopilot was instructed to cross the geo-fence, which was successfully prevented by the algorithm.

Geo-Fencing



Power Model



To evaluate the power model, a trajectory consisting of curves, ascents, and descents was executed by the autopilot. The propulsion power model showed errors ranging from negligible to approximately 5%. Furthermore, the model showed similar results in the Emulation Environment incorporating Power-Awareness into uavEE.

FUTURE WORK

- Integrate Solar Model
- Extend Kinematic Model
- Power-Aware Path Planning using the Kinematic Model
- Long Endurance Solar Powered Flight

REFERENCES

[1] M. Theile and S. Yu, "Kinematic Model for Fixed-Wing Aircraft with Constrained Roll-Rate," tech. rep., University of Illinois at Urbana-Champaign, Department of Computer Science, Sep 2018.
[2] O. D. Dantsker, M. Theile, and M. Caccamo, "A high-fidelity, low-order propulsion power model for fixed-wing electric unmanned aircraft," AIAA/IEEE Electric Aircraft Technologies Symposium, Jul. 2018.
[3] M. Theile, O. D. Dantsker, R. Nai, and M. Caccamo, "uavEE: A Modular, Power-Aware Emulation Environment for Rapid Prototyping and Testing of UAVs," IEEE International Conference on Embedded and Real-Time Computing Systems and Applications, Hakodate, Japan, Aug. 2018.

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