National Aeronautics and Space Administration

System Level Prognostics Framework for a UAV Powertrain System

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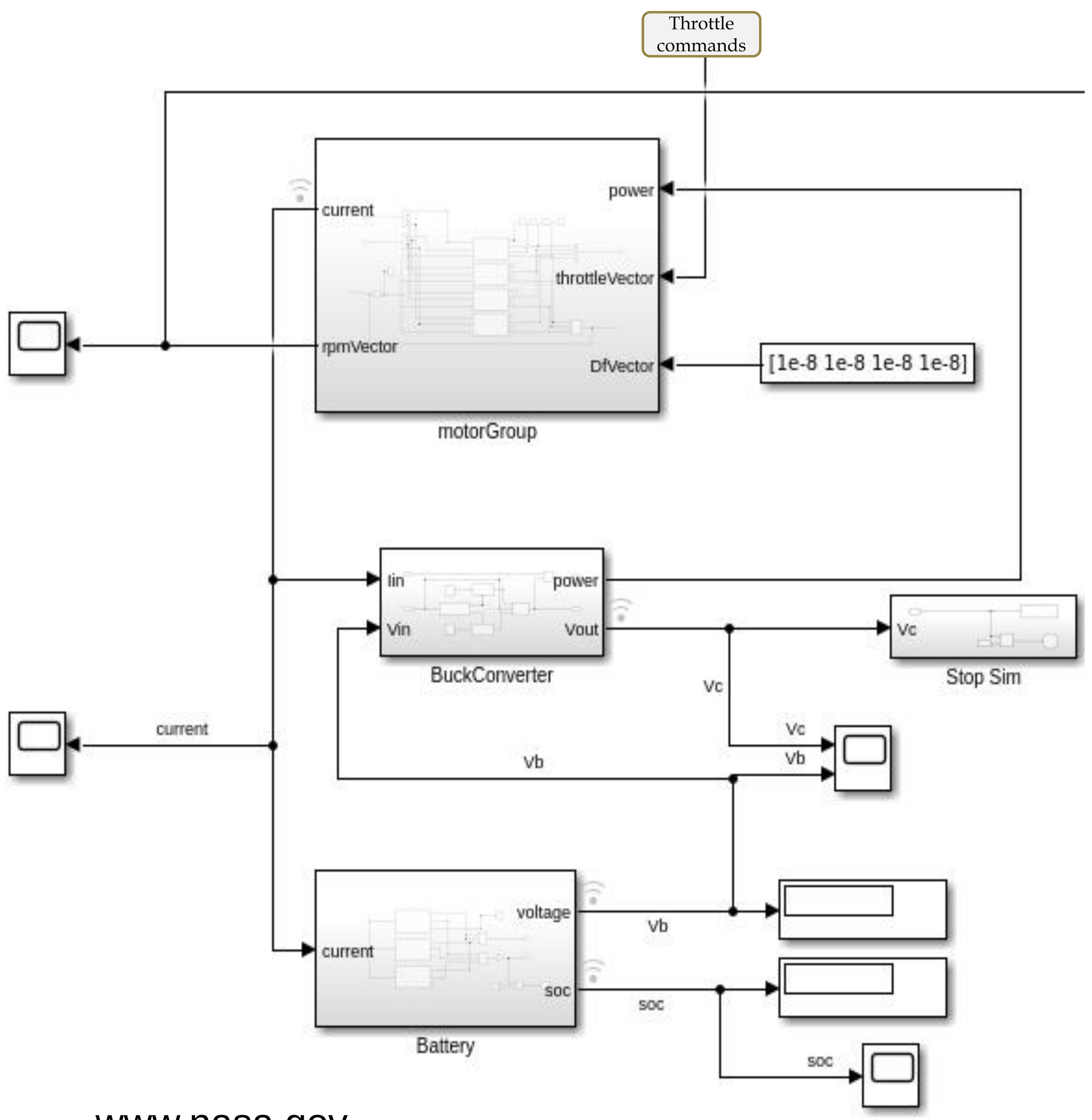
Abstract

Within the last decade, progress toward developing a practical electrically-powered transport aircraft has accelerated with improvements in battery technologies and advanced algorithms to control and monitor safety critical processes. Online estimation methodologies to reason about faults and component degradation are critical to the safety of the aircraft, its occupants, and the success of its mission. We hypothesize that utilizing a holistic approach to system level prognostics and health management will result in a robust framework which can be applied to several safety-critical systems. We apply this methodology to the power-train system of the DJI Mavic Pro quad-copter and subject the system to multiple degradations at the same time to demonstrate the system level prognostic capabilities.

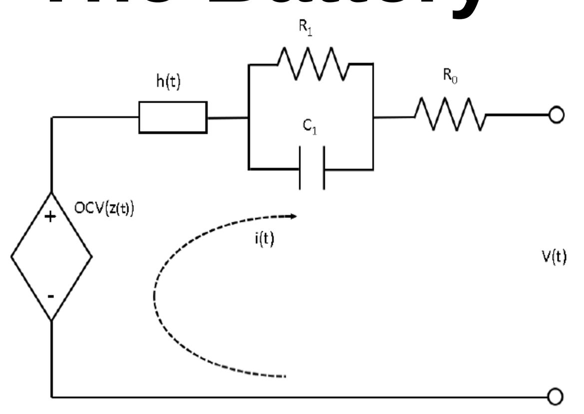
DJI Mavic Pro Powertrain

The powertrain system consists of a 3 cell battery, a buck converter (power condition circuit), and the motor group.



The Battery

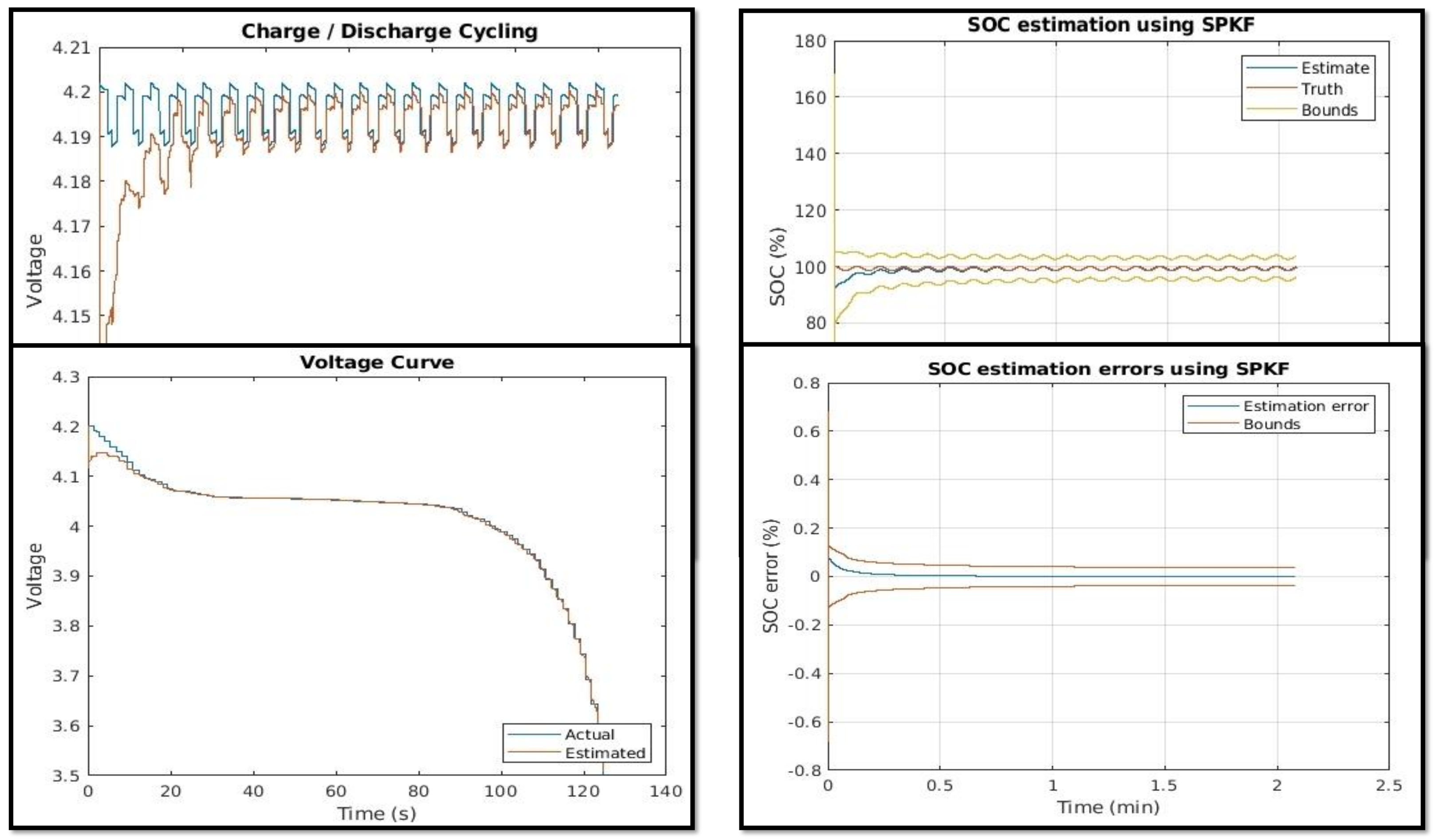
The battery is modeled as a modified Thevenin cell and accounts for hysteresis, diffusion voltages, Warburg impedance, and coulombic efficiency.



$$z[k+1] = z[k] - \frac{\eta[k]\Delta t}{Q} i[k]$$
$$i_R[k+1] = I_{mat} i_R[k] + (1 - I_{mat}) i[k]$$
$$h[k+1] = H_{mat} h[k] + (H_{mat} - 1) sign(i[k])$$
$$v[k] = ocv(z[k]) + M_0 sign(i[k]) + M h[k] - \sum (R i_R[k]) - R_0 i[k]$$

Parameter	Value
Q	$3800mAh$
η	.9929
γ	.1199
M_0	$1e^{-4}$
M	$1e^{-6}$
R_0*	$.0112\Omega$
R_1	$.1\Omega$
C_1	250μ F
V_0	$4.2v$

** Degradation parameter*

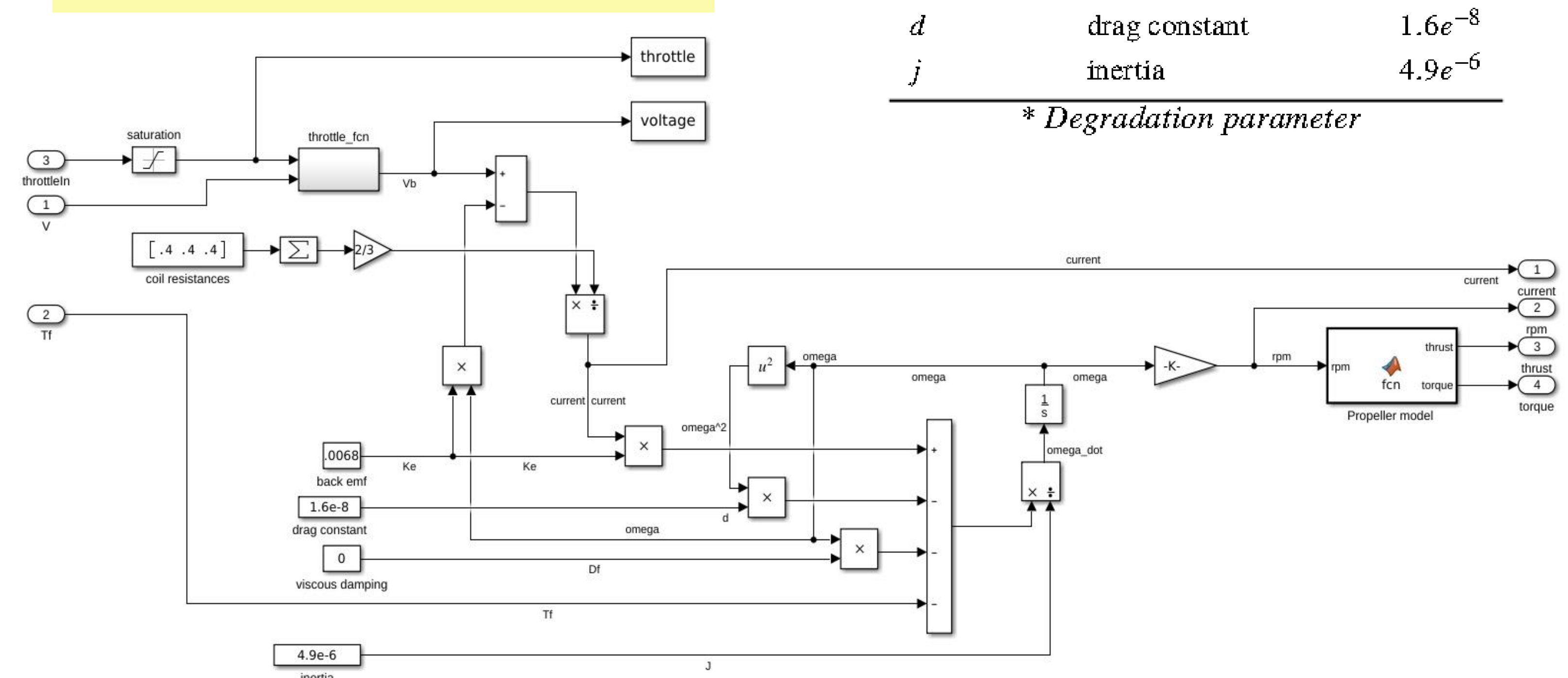


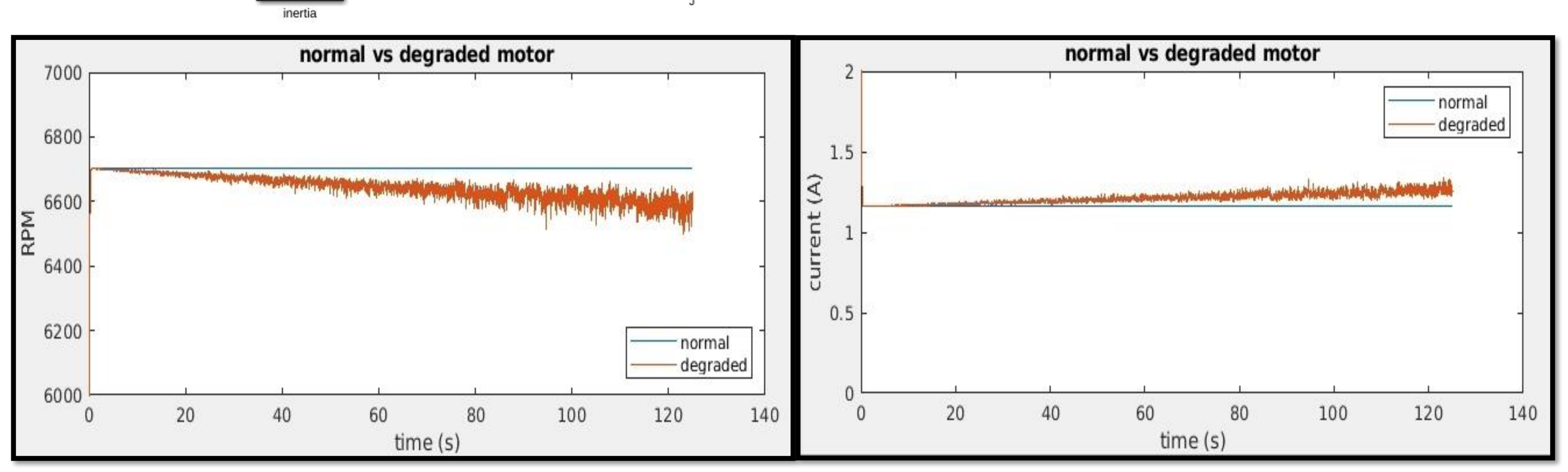
The Motors

The motors are modeled as simplified permanent magnet DC motors with similar performance characteristics as the more complex BLDC 3 phase AC motor.

Parameter	Desc	Value
R	coil resistance	$.8\Omega$
Ke	back EMF	.0068
$Tf*$	friction torque	$1e^{-8}$
Df	viscous dampening	$1e^{-9}$
d	drag constant	$1.6e^{-8}$
j	inertia	$4.9e^{-6}$

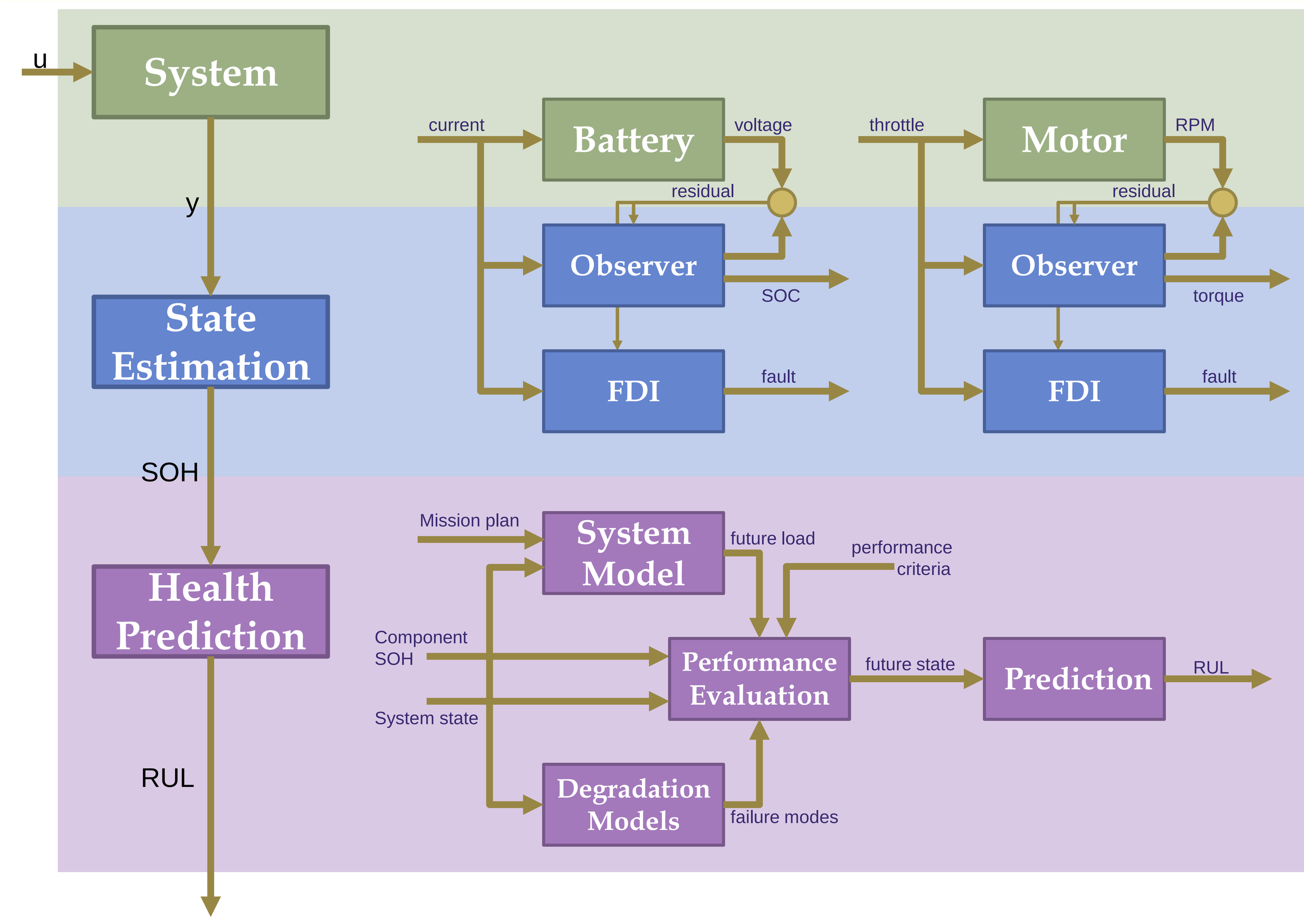
** Degradation parameter*





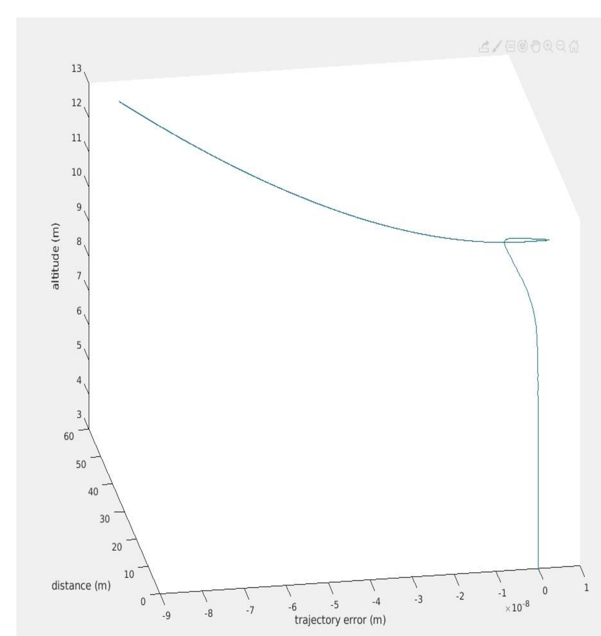
Prognostics Architecture

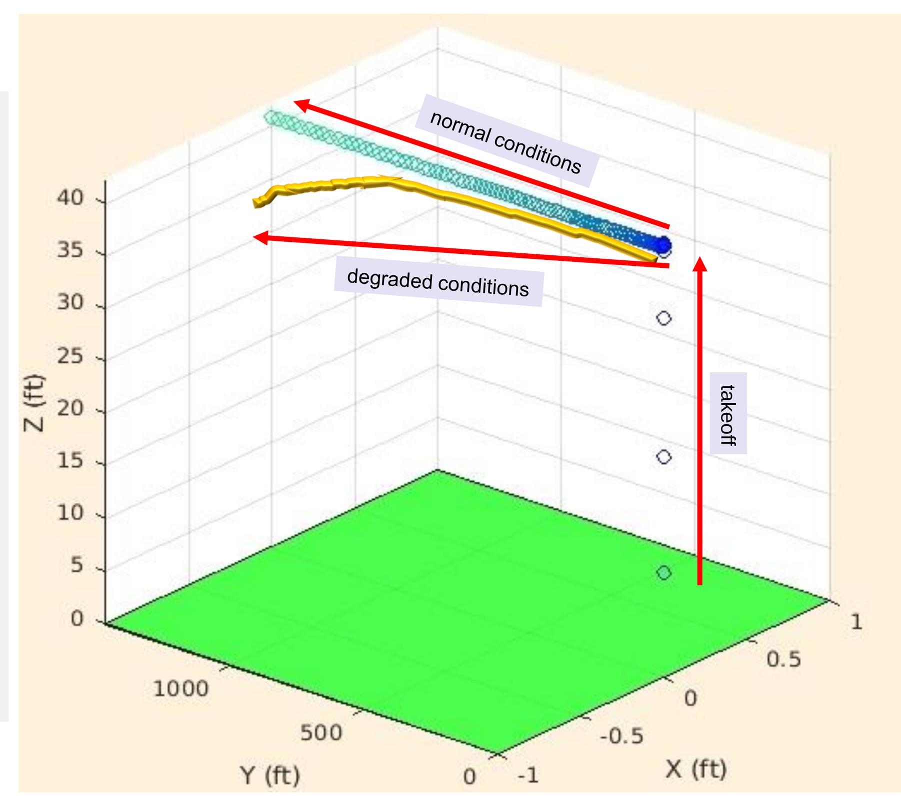
The prognostics architecture expands upon a two-step process of state estimation and RUL prediction of individual components to that of the entire system. Each component has its own observer and FDI pipeline (not discussed in this work). Data from the observers and expected future input are fed to the prediction step to update the RUL of the system given a set of constraints and performance criteria.



Results

Preliminary results suggest the above framework for system level prognostics is accurate, robust, and works well under varying degrees of uncertainty. The figure below and right depicts the deviated trajectory of the UAV under degraded conditions. The figure below and left is a close up of the trajectory from takeoff to shortly after reaching altitude.





Future Work

This is an ongoing project and work continues to finish implementing the observer for the motor and the particle filter for the prediction step. Once the proposed methodology has been fully realized we will add decision making into the loop for route selection and payload weighing for delivery applications.

Acknowledgements

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