Energy Modeling and Optimization for Delivery Quadcopters

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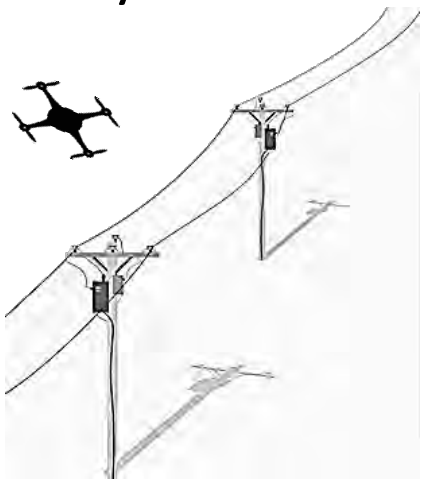
Introduction

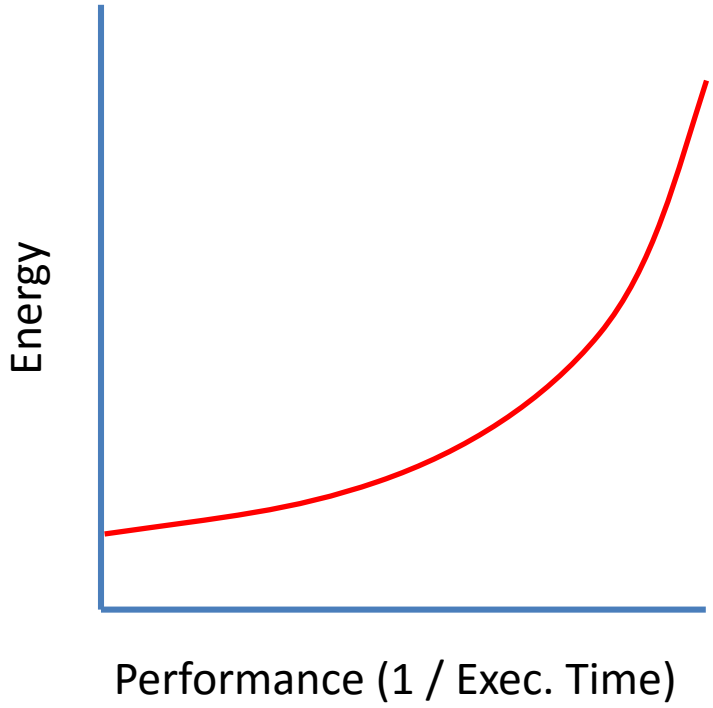
- Backgrounds
  - Automated drones are considered as promising delivery vehicles in near future
    - E.g., Amazon
  - Running out of battery during flight may result in tragedy

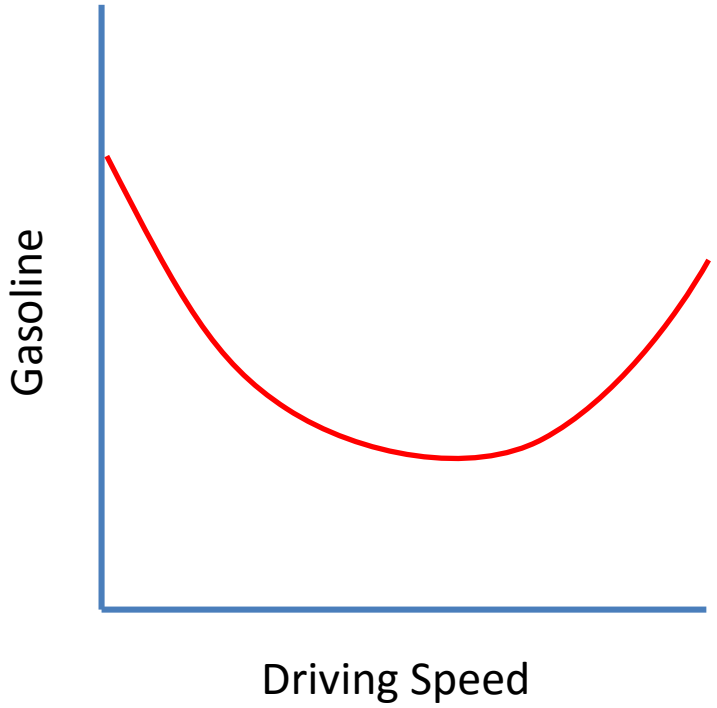


- This work
  - Power measurement and modeling for quadcopter drones
  - Routing optimization for multi-destination delivery

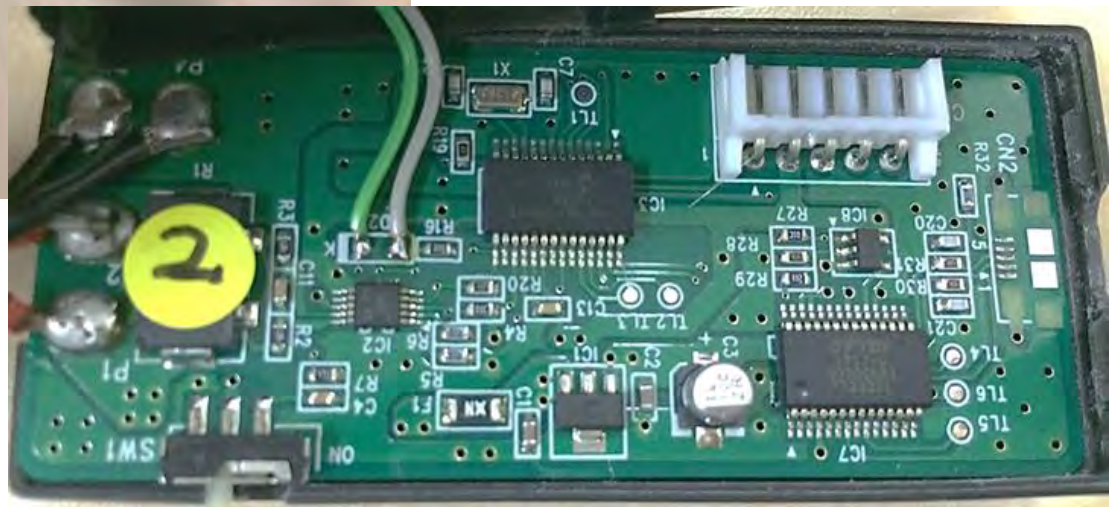
Energy-Performance Examples

- DVFS-enabled LSIs
  - Monotonic
  - Higher performance consumes higher energy
- Petrol automotive cars
  - Convex
  - 60-80 km/h is the most gas-efficient



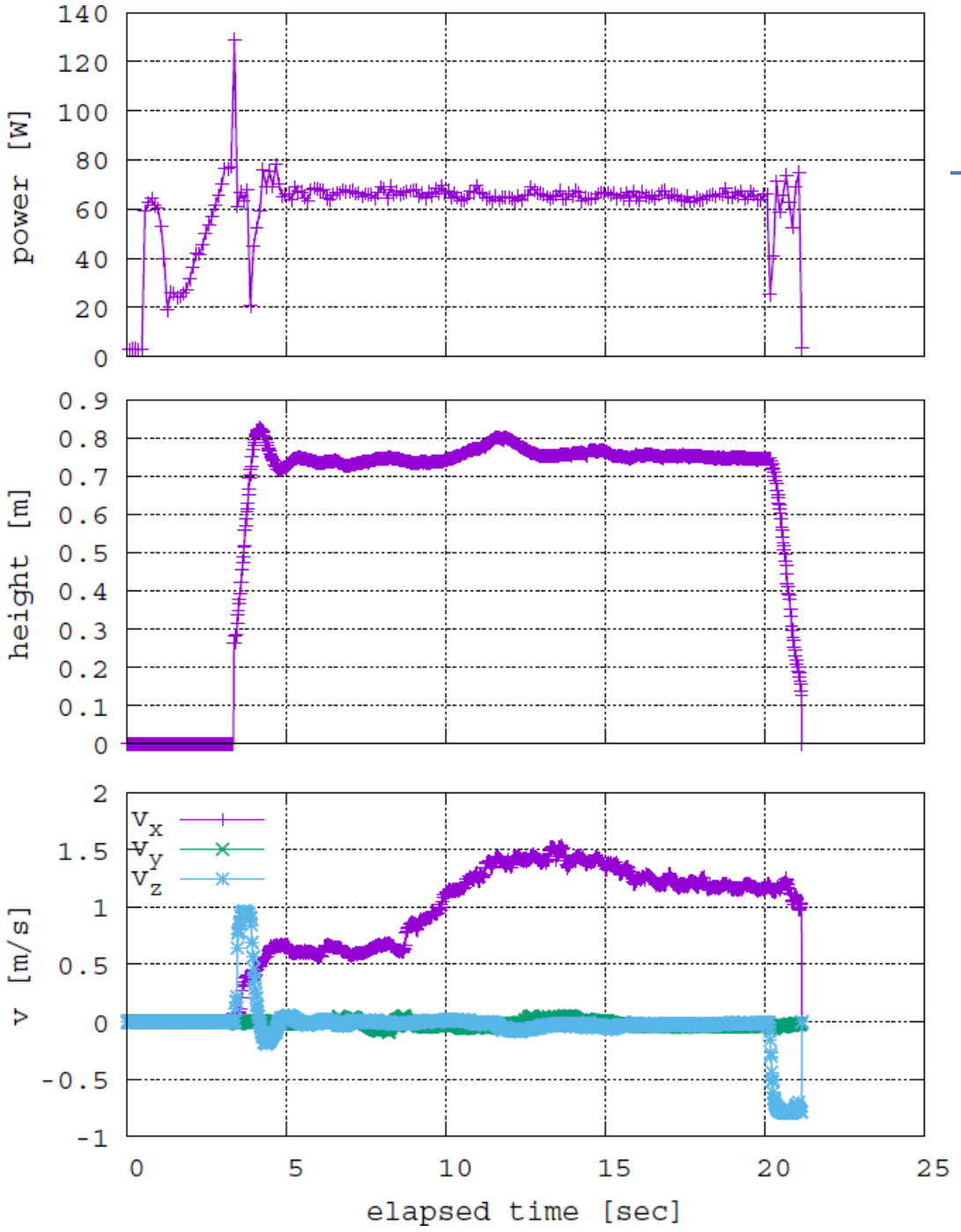


Power Measurement of A.R.Drone 2.0

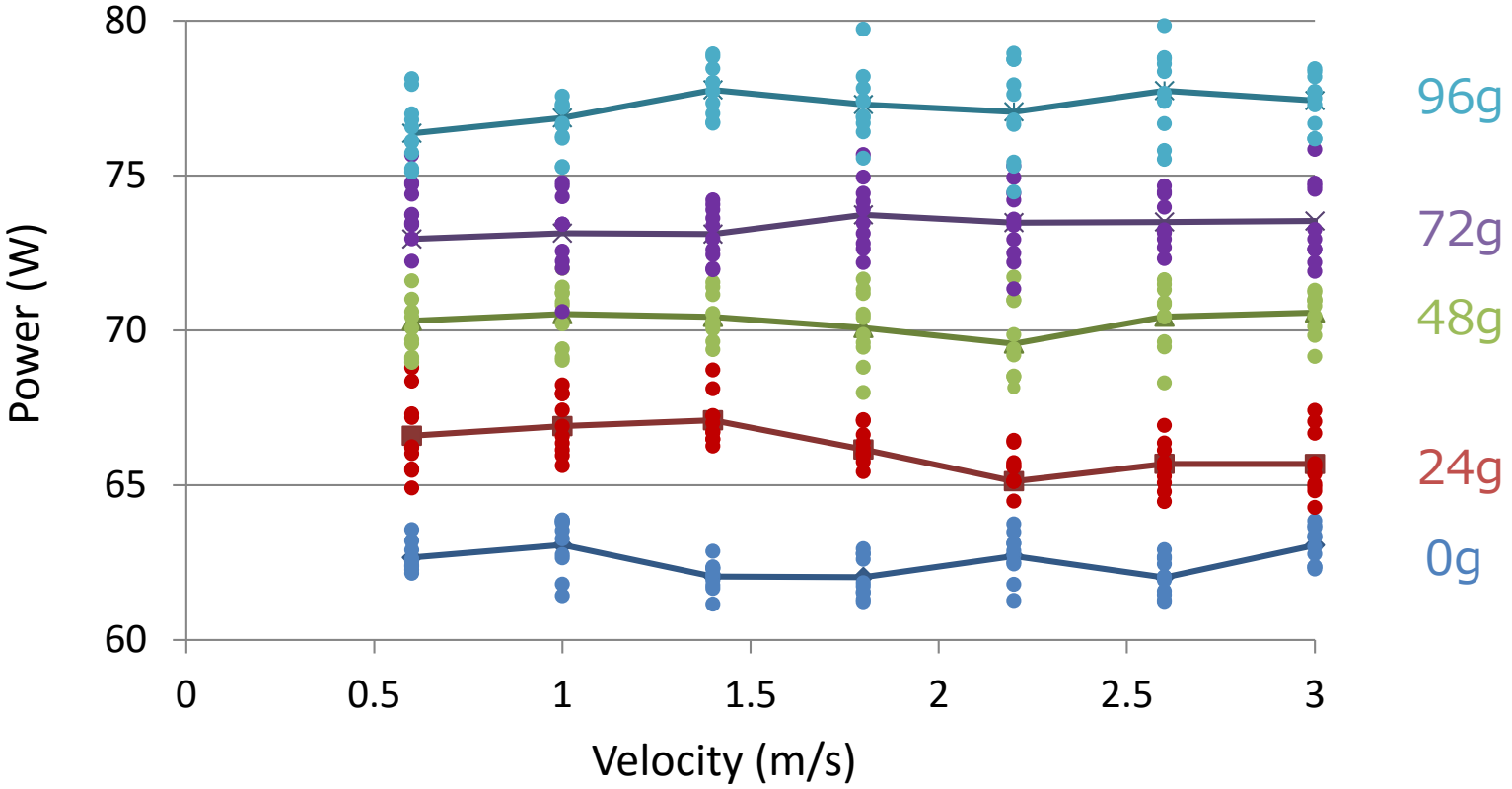


Measurement Example

- Power
  - Calculated by voltage and current
  - Sampling period: 100 ms
- Height from the ground
- Velocity
  - X: traveling direction
  - Y: cross direction
  - Z: vertical direction
  - Sampling period: 30 ms

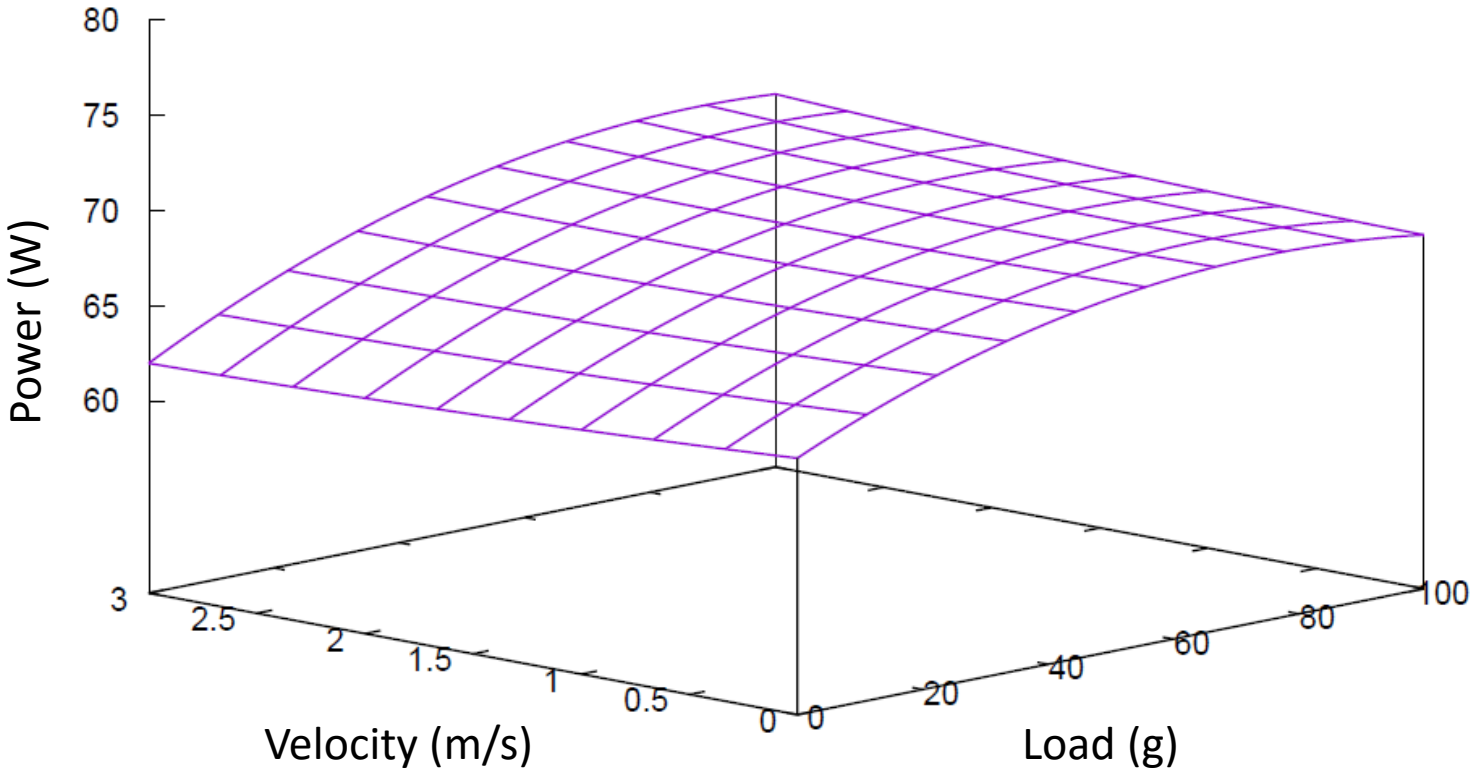


Load-Speed-Power Results



- Flight speed does not affect power consumption very much.
  - Most power is consumed for keeping the body in the air.
- Power is nearly linear to load.

Regression Analysis



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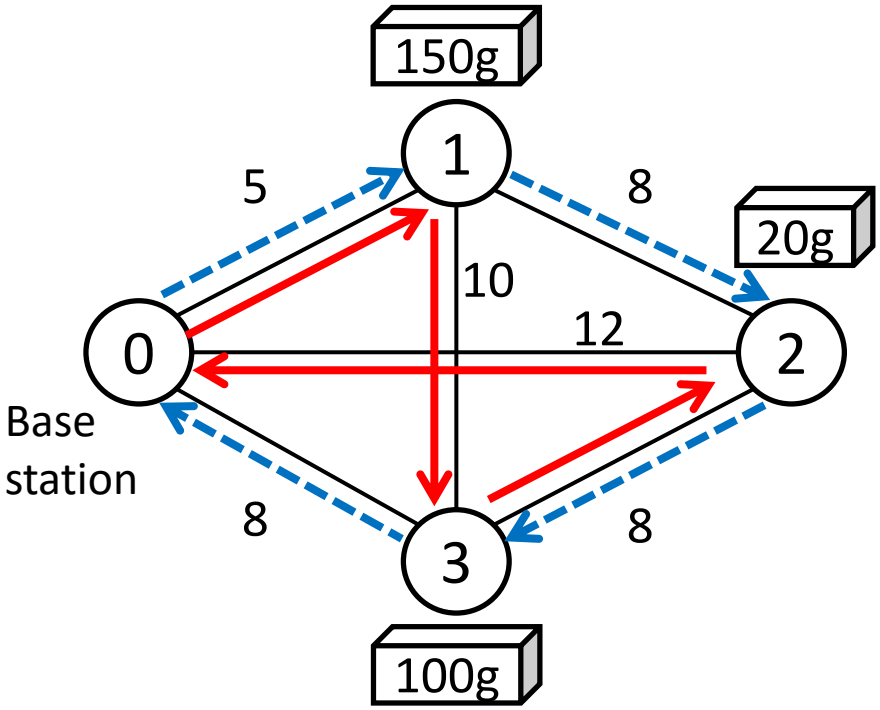
Modeling of Energy Consumption

- Flight at the fastest speed results in minimum energy
  - Energy = Power x Time
- We simply model the energy as a function of *distance* and *load*

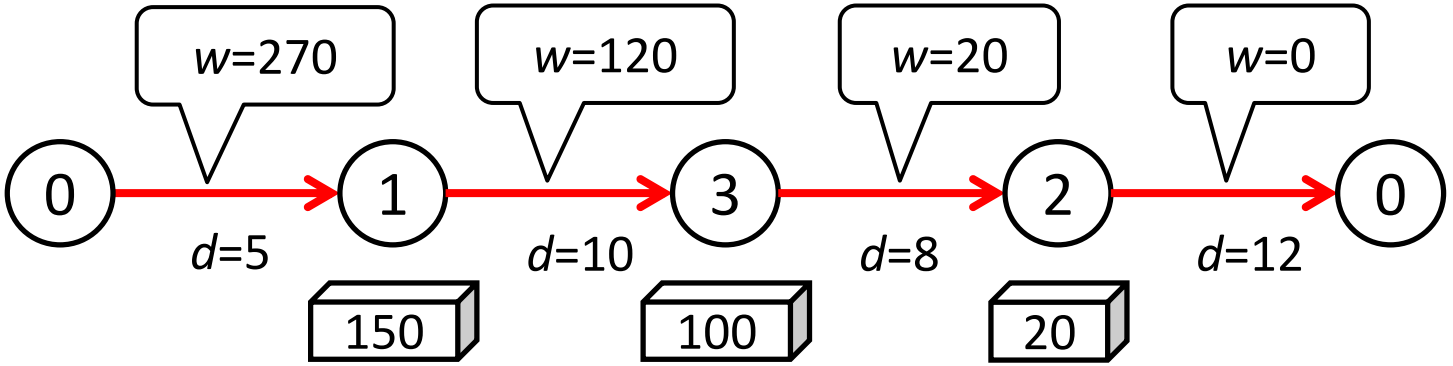
$$Energy = f(distance, load)$$
$$= \alpha \cdot distance \cdot (load + \beta)$$

- α and β are coefficients determined by the quadcopter

Delivery Routing Problem



- Given
  - A set of items to deliver
    - Each item are associated with
      - place to deliver
      - weight
  - Distance between the places
- Goal
  - Find a route with minimum energy



Delivery Routing Optimization

- Extension of TSP (traveling salesman problem)
- Three algorithms
  - Nearest neighbor first
  - Heaviest item first
  - Exhaustive (optimal)
- Experiments with randomly generated problems

Normalized Energy (Exhaustive=1.000)

Problem ID	# Items	Nearest first	Heaviest first
1	4	1.000	1.790
2	4	1.003	1.030
3	4	1.080	1.006
4	6	1.160	2.400
5	6	1.310	1.040
6	6	1.160	1.460
7	8	1.320	2.160
8	8	1.070	1.640
9	8	1.000	2.720
10	10	1.270	2.120
11	10	1.080	2.400
12	10	1.200	2.180

Summary

- Energy measurement and modeling of quadcopter drones
  - Speed has little impact on power
    - Fly fast for energy minimization
  - Load has linear impact on power
    - Routing is important
- Delivery routing optimization
  - Extension to traveling salesman problem
- Special thanks
  - Ittetsu Taniguchi
  - Kotaro Maekawa
  - Shunsuke Negoro