.

Energy Aware Coverage Path Planning of UAV’s

Presented By:

Farhan Ajmal Khan - 1736413

Muhammad Haris Bukhari – 1789066

(As Elective in Robotics)

.

Contents

.

1 INTRODUCTION

In todays world UAV's have started to evolve a lot in aerial based applications and has transformed usage of airspace. We have seen many innovations like drone taxi which is yet to be introduced in Dubai. And then its military use in different air forces of the world for surveillance and missions. More over this concept is still being pushed on as a startup company produced fire fighter drone and then there is world's largest retail online shopping giant "Amazon", delivering their products from drone. From military to commercial use it has covered a span of almost two decades.

It is a big achievement in itself but more over there is a role of "Artificial Intelligence" which has led people to develop sophisticated algorithms for autonomous flights. Autopilots have already stepped into market and now its time for vision based deep learning to enhance the system.

Unmanned Aerial Vehicles (UAVs) are starting to be used for photogrammetric sensing of large areas in several application domains, such as agriculture, rescuing, and surveillance. Still the key element in todays drone flight is energy management and path coverage. This project discusses these issues in detail regarding the optimal energy calculation for a particular path. Paper also proposed an algorithm for path planning for convex maps, but we didn't include it in our project due to complexity. Our prime focus was on the energy calculation of a path.

2 SYSTEM MODEL

There is quadcopter with camera mounted on the lower for photogrammetry. The objective of the mission is to reconstruct image of a given area with spatial resolution R no lower than *Rd in pixel/cm.*

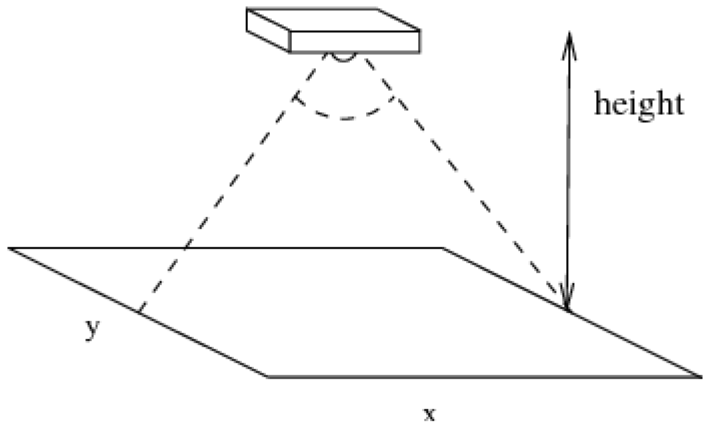
We assume that images are taken by a video camera having the following parameters:

1) Angle of view (AOV), α (expressed in radians), that is, the angular extent of a given scene that is imaged by the camera
2) Image Resolution (I_x, I_y), expressed in pixels for both image sides
3) Aspect ratio ρ, that is, the ratio between the image width and image height ($\rho = I_x/I_y$);
4) Minimum sampling period T^{min}, that is, the minimum interval between two consecutive shots

If the camera is exactly parallel to the ground (this assumption can be done considering the camera stabilizer), the size (L_x, L_y) of the projected area can be computed as

$$L_x = 2h \cdot \tan\left(\frac{\alpha}{2}\right)$$
$$L_y = L_x/\rho$$

.



$$R = \frac{I_x}{L_x} = \frac{I_x}{2h \cdot \tan\left(\frac{\alpha}{2}\right)}. \quad (2)$$

Substituting equation (2) into the inequality constraint of the mission of required resolution that Is the Resolution should be higher or equal to the R_d, We have:

$$h \leq \frac{I_x}{2R_d \cdot \tan\left(\frac{\alpha}{2}\right)}. \quad (3)$$

Thus the maximum height that the quadcopter is allowed to fly becomes

$$h_{max} = \frac{I_x}{2R_d \cdot \tan\left(\frac{\alpha}{2}\right)}. \quad (4)$$

This way we can calculate the max height at particular desired spatial resolution which can be set by the user.

.

3 BUILDING ENERGY MODEL:

The building of energy model was setup by using real drone and there were sensors like accelerometer and electrical meters to get the consumption of the energy by the drone. It was in different experiment phases to ensure everything is covered up

We measured the energy consumed by the quadrotor during all the possible trajectories (acceleration, deceleration, constant speed…).

Testbed: IRIS quadcopter

- px4 autopilot
- Weight: 1.2 Kg
- Battery 5500 mAh

4 EXPERIMENTS:

In a first experiment, the drone was programmed to run at the maximum acceleration and deceleration, monitoring the speed from the onboard GPS and the absorbed current from the control board. The consumed power was then derived by multiplying the absorbed current by the supply voltage, for each speed. Figure below shows the speed and the power acquired under maximum acceleration, along with the corresponding fitted curves. Similarly, Figure below shows the same quantities acquired under maximum deceleration

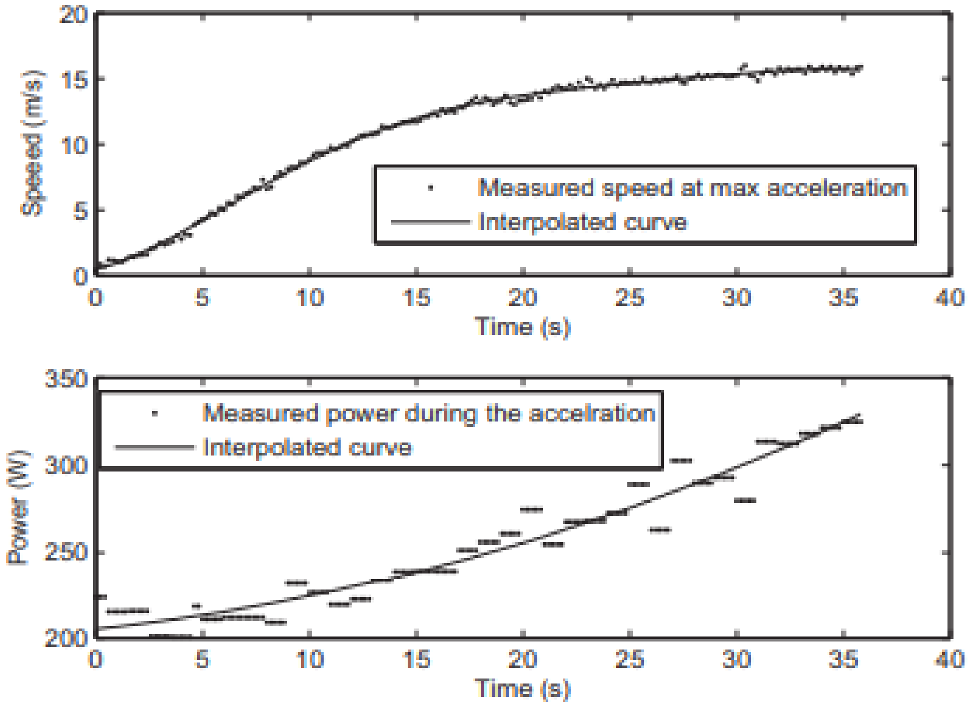
Thus, the energy consumed to vary the speed from v_1 to v_2 with a given acceleration a can be computed as

$$E_a = \int_{t_1 : v = v_1}^{t_2 : v = v_2} P_a(t)\, dt.$$

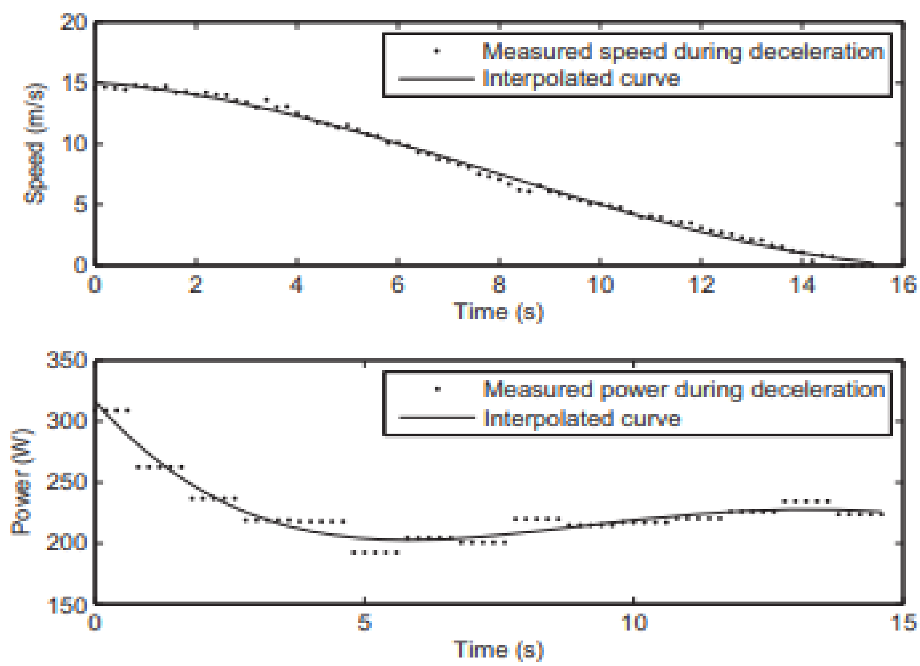
.

4.1 FIRST EXPERIMENT

4.1.1 Acceleration:



4.1.2 Deceleration:



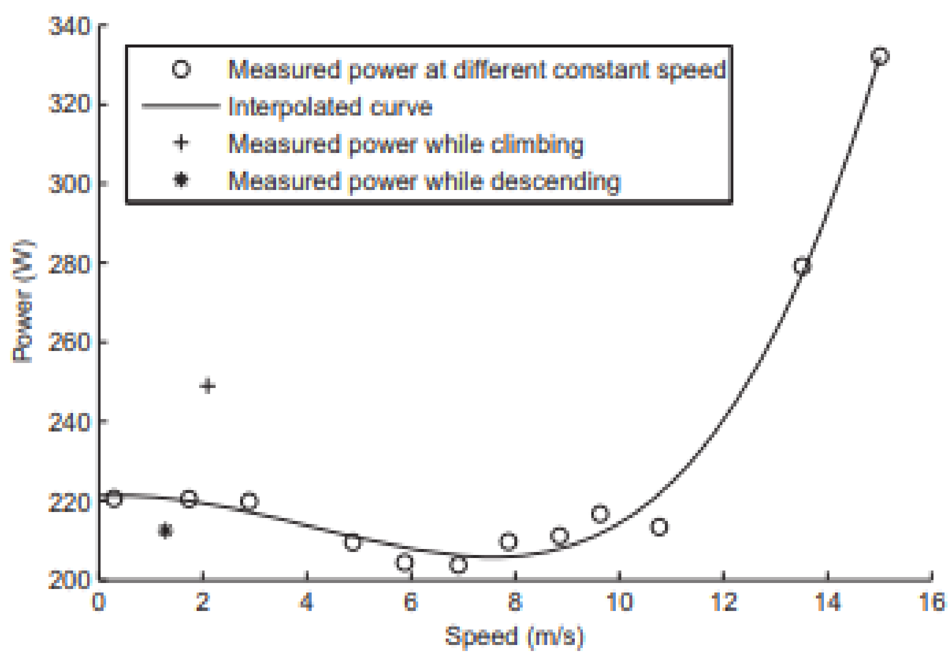
.

4.2 SECOND EXPERIMENT:

In a second experiment we derived the power consumption as a function of the speed in different flight conditions, such as horizontal flight, climbing, descending, and hovering. The results of this experiment are reported in Figure, which also shows the fitted curve. Note that, since the climbing and descending operation is always performed at a constant speed, the corresponding power consumption is plotted as a single point in the graph corresponding to that speed. Also note that the power consumed during hovering corresponds to the point in the graph for $v = 0$.

The energy consumed in a straight flight to cover a distance *d* at a constant speed *v* can be computed as

$$E_v = \int_0^{d/v} P(v)\, dt = P(v)\frac{d}{v}.$$



.

4.2.1 Energy for Climbing and Descending:

$$E_{climb} = \int_{h_1/\hat{v}_{climb}}^{h_2/\hat{v}_{climb}} P_{climb}\, dt = P_{climb}\frac{\Delta h}{v_{climb}}$$
$$E_{desc} = \int_{h_2/\hat{v}_{desc}}^{h_1/\hat{v}_{desc}} P_{desc}\, dt = P_{desc}\frac{\Delta h}{v_{desc}}$$

4.3 THIRD EXPERIMENT:

The third experiment was done to measure the power required for turning and rotations. With angular rotation speed w (2.1 rad/sec) and power (225 watts/sec). Change in angle is considered to be Δ theta.

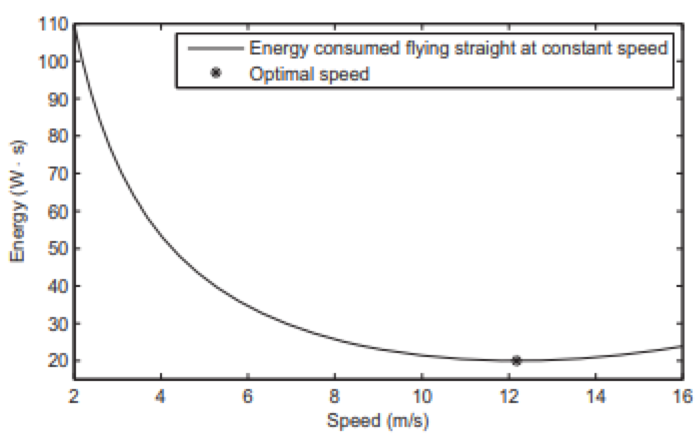
$$E_{turn} = P_{turn}\frac{\Delta\theta}{\omega_{turn}}.$$

4.3.1 Optimal Speed:

4.3.1.1 Constant Speed:

The energy consumed by the UAV during a straight flight at constant speed *v* to cover a distance *d* is expressed by Equation. Figure below shows how this energy changes with the speed. As evident from Figure below the curve has a minimum for a speed v^* is 12 m/s, which can be computed as:

$$v^* = \min_v P(v)\frac{d}{v}.$$



.

4.3.1.2 Variable Speed:

One solution to energy minimization problem would be dividing the trajectory into three phases: Acceleration phase , constant speed and deceleration in the end. The combined phase would be equal to whole distance d. Hence the optimal speed v* can be found by minimizing the function below:

$$E(d) = \int_0^{t_1} P_{acc}(t)\, dt + \int_{t_1}^{t_2} P(v)\, dt + \int_{t_2}^{t_3} P_{dec}(t)\, dt$$

where P_{acc}, $P(v)$ and P_{dec} are the functions derived from the experiments reported in Section III-A by interpolating data with fifth order polynomials, and

$$t_1 : v_{acc}(t_1) = v \qquad (15)$$

$$t_2 = \frac{d - d_{acc} - d_{dec}}{v} = \frac{d - \int v_{acc}(t_1)\, dt - \int v_{dec}(t_1)\, dt}{v} \qquad (16)$$

$$t_3 : v_{dec}(t_3) = 0 \qquad (17)$$

Figure below shows the energy consumed as a function of the maximum speed for different given distances *d* whereas Figure 8 reports the optimal speed as a function of the covered distance *d*. Note that for long distances ($d > 1$ Km) v^* tends to the optimal value computed assuming constant speed. This result allows us, to compute the optimal speed that minimizes the energy consumption for each straight line of length *d* during the path.

.

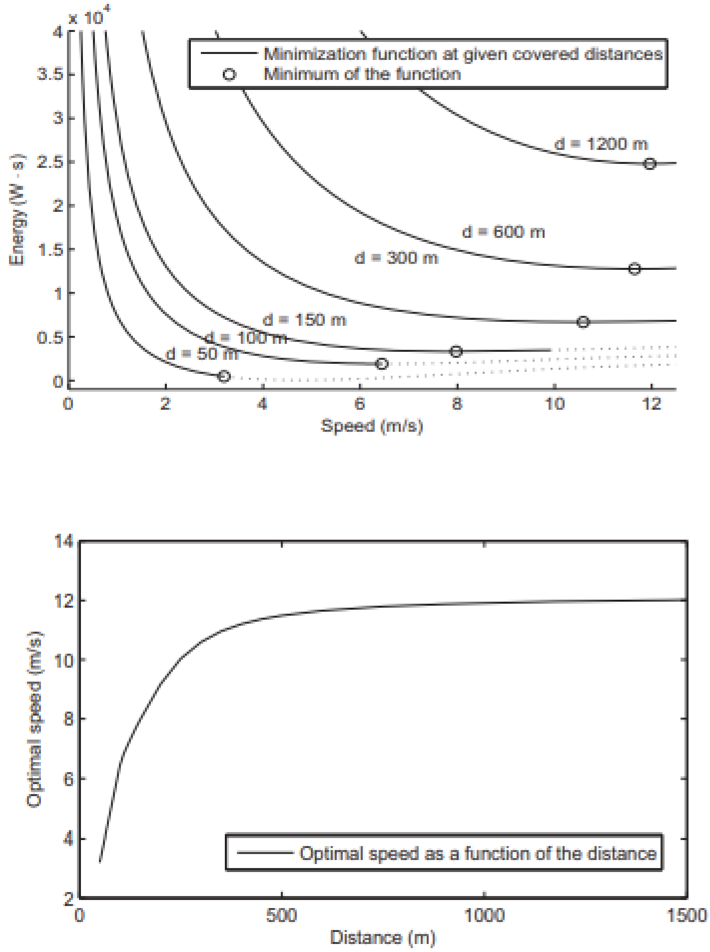


Fig. 8. Optimal speed as a function of the covered distance d.

.

5 CONCLUSION:

This paper presented an energy-aware path planning algorithm that computes a path for achieving the full coverage of a given survey area, taking into account other constraints, namely the available energy, the minimum spacial resolution for the pictures, and the maximum camera sampling period. The paper described a method for deriving an energy model of a specific UAV starting from real measurements. Using such a model, the proposed algorithm computes the speed that minimizes energy consumption along a given distance. Once the full path is generated, it is possible to derive the speed that minimizes the energy consumption for each segment in the path. Then, a feasibility test is performed to verify whether the energy available on the UAV is sufficient to scan the entire area.

.

6 REFERENCES

[3] C. Di Franco, Buttazo G., “Energy aware Coverage Path planning of UAVs” IEEE conference on Autonomous Robot Systems and Competitions (ICARSC 2015), April 8-10, 2015, DOI 10.1109/ICARSC.2015.17

[2] E. Galceran and M. Carreras, “A survey on coverage path planning for robotics,” *Robotics and Autonomous Systems*, vol. 61, no. 12, pp. 1258–1276, 2013.

[3] Y. Mei, Y.-H. Lu, Y. C. Hu, and C. G. Lee, “Deployment of mobile robots with energy and timing constraints,” *Robotics, IEEE Transactions on*, vol. 22, no. 3, pp. 507–522, 2006.