# Intro to UAV - Project Report

# Real time Surveillance in Windy/harsh weather conditions with Trajectory Tracking

# Quadrotor - Pelican

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## Aim and Objectives:

- To get the basic conceptual design phase understanding of the application
    - CONOPS
    - Requirements and Market Survey (esp. For weather-proof drones)
    - Design Analyses
- To explore and use the RotorS repository with ROS, Gazebo and RViz to simulate the necessary aspects of this project
- To learn to add sensors and find a way to visualise it
- To visualise wind, using Paraview software
- To implement and execute real time trajectory tracking with camera feed with and without wind
- To tune the control parameters appropriately to achieve stable flight

## Content and Workflow:

- Problems of flying under harsh weather
- User Requirements and CONOPS
- Market Survey and Specifications
- Component Identification and Design
- Simulation Details - step by step procedure and explanation (all achieved with wind and without wind)
    - Achieved drone and environment design close to the application
    - Achieved **stable flight**
    - Achieved **Trajectory tracking**
    - Achieved live and **real time image/video** data visualisation from pelican's camera in **RViz**
- **Wind Visualisation** - Paraview software

## Problems with flying in extreme conditions:

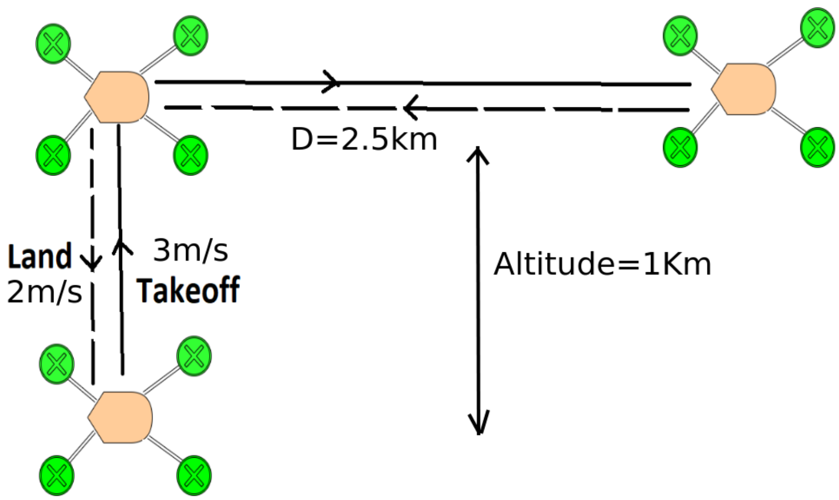
- Battery life is severely affected as the drone has to overcome wind, especially in upstream
- We can expect wind speeds ranging 5 - 8 m/s for this application/design.
- In high altitudes, besides wind, there can be motor failure and blurring of camera lens (This would be disastrous when camera is a part of path planning or crucial flight requirements)
    - Low temperatures
    - Condensation due to moisture and fresh snow
    - Heavy Rain (if the drone is waterproof,  to model the rain, we can consider the force acting on the drone as similar to wind)
    - Low light (visibility of the surroundings and the drone) to overcome this, we need high-visibility lights on the body of the craft.
    - Wind during takeoff and landing is more challenging than cruise.
    - Precautions like listed in [3] can be taken to avoid crashing in such conditions

## User Requirements:

- At least 25 min of flight time
- Max Altitude 1 KM (default can be 200 - 500 m) above the sea level
- It is needed to work in high windy areas (5  - 8 m/s)
- It has to operate within a distance of 1KM and come back to the home point.
- The drone is needed for surveillance and real time camera feed.
- For surveillance, specific points or trajectory is given and it has to follow it.
- **Note:** Here, we are considering a high altitude region of wind. Temperature and rain can be tackled in a similar way but we need to build a waterproof cover, as in PowerEggX shown in the market survey.

## CONOPS:

- Climb to an altitude of 1km.
- Follow the trajectory and capture the images and render them on rviz as real time video feed
- Return back to the location of takeoff (as per the specified trajectory)
- Descent and land (as specified by the trajectory)




Most of the drones which can be used in rain or snow or heavy wind conditions or high altitudes (with necessary precautions and provided guidelines) are termed weatherproof in the market. Some of such drones which are close to satisfying the current requirements are explored and their specifications are mentioned here.

## Market Survey - 1

**PowerEgg X Specs (water proof)**
Take off weight = 0.89 kg
Dimensions = 7× 4 × 4 in
Endurance = 30 min
Working temperature = 32F - 102F
Max Ascent Speed = 5 m/s
Max Descent Speed = 3 m/s
Max Flight Speed = 18 m/s
Range = 6 KM
Max Wind Speed Resistance 8 - 10 m/s (level 5)
Altitude ~ 5KM

## Market Survey - 2

**Splash drone 3+ (water proof)**
Drone Weight: 1447g
Max Ascend Speed: 4m/s
Max Descent Speed: 3m/s
Max Flight Speed: 18m/s
Max Flight Altitude: 1.3 KM
Max Flying Wind Speed = 8 - 10 m/s
Endurance = 20 - 23 min
Payload = 1 KG
Max take-off weight ~ 3 kG
Max flight range = 1.6km

## Market Survey - 3

**DJI Mavic 2 Pro**

Takeoff Weight: 907 g
Maximum Takeoff Altitude: 6000 m
Endurance: 30 min (29 in wind)
Range: 18 KM (at 13.8 m/s)
Wind speed resistance: 8-10 m/s

## Requirement Specifications:

Final specifications based on User requirements and market survey are as follows

- Mass (max takeoff weight) = 1.2 kg (including battery and camera)
- Endurance = 30 min
- Wind resistance = 5 - 10 m/s
- Max altitude = 1 KM
- Range = 4 KM (conservative) (to and fro)
- Max Ascend Speed = 3 m/s (initial consideration)
- Max Descent Speed = 2 m/s (initial consideration)
- Max flight/cruise speed = 10 m/s
- Battery considered = 4000mAh (11.4 V)

1.2 kg is considered because, we wanted to start off with 1.0 kg itself but we added the camera as payload, this 1 kg is supposed to include all the components in itself, but to account for the possible use of a different battery and additional sensors (IMU, Odometry, etc), we started off with 1.2 kg. This is clearly explained in the next section.

## Sizing and Component Identification:

- Some sensors are added to the already existing basic sensors in pelican.xacro and pelican_base.xacro file
- Battery, rotors, GPS, Accelerometer, Gyroscope, Magnetometer, Altimeter are default in the autopilot scheme (wt. Accounted in max takeoff weight.)
- Generic Odometry sensor (~15g to estimate the change in the position of the UAV, using other motion sensors) is available in the model and weight accounted for.
- Similarly, IMU sensor (7g to measure the external force and angular rates)
- Camera - 100 g (payload for video/camera real time data) is added.
- Rotors mass is 20*4 = 80g (weight accounted)
- Body width = 100cm, height = 200cm (weight accounted)
- LED lights = 5g (weight accounted)

Therefore, we conservatively considered mass as 1.2kg.

LEDs are necessary because, as mentioned in the ‘problems due to wind section’ above, the detectability of the drone will be high.

Basically, we can assume all the weight due to all the sensors is included in the mass ie. 1kg which we initially considered. But to account for more battery which we need to fly in the wind and harsh weather, we added 100 g from its side and 100 g from the added camera payload.

## Design and Analysis:

For the calculation of hovering time, we assumed for each trajectory point, UAV hovers for 10sec to capture a image, for this calculation, we assumed that there are 1500 way-points and total hover time is1500 sec

**Take-off**

$T > 0.25 * mg$

$T > 2.94N$

**Climb**

$4Tc = mg + (0.1021 * climb\,rate^2)$

$T_c$= 3.169N

**Cruise**

$\theta = arctan(\frac{0.1021x100}{mg})$

$Tcr = \frac{mg}{cos\theta} = 15.57N$

**Hover**

$Th = mg$

$Th = 11.76N$

**Descent**

$4Td = mg - (0.1021 * climb\,rate^2)$

$T_d$= 2.83N

**Energy calculations**

$$E_r = P_c t_c + P_{cr} t_{cr} + P_h t_h + P_d t_d$$

$$P_c = T_c V_c$$
$$P_{cr} = T_{cr} V_{cr}$$
$$P_d = T_d V_d$$

$Er = 12676 + 31140 + 95010 + 11350 = 150,176J$

$Ebr = \frac{Er}{\eta=0.65}$ $Ebr = 231040J$ $Eb = 11.4 * 6 * 3600 = 246240J$

Endurance = 42min

Range = 2km+0.72=2.72km

We see that the specs are satisfied, but some compromise on the range.

## Controller Tuning:

In the present scenario, we are using the inbuilt or the provided LEE controller in RotorS repository. The controller has Kp (proportional gain), KD (derivative gain) and KI(integral gain), it is as far as we understand the same as PID controller.

We observed the tuned parameters already available in the repo. By varying mass, inertial, we observed that these gains need to be tuned again. With the addition of wind plugin also, we tried to vary KI so that the overshoot from the given waypoint reduces a little bit.

The steps (including attempts and observation) we followed in tuning the controller - Mostly trial and error based approach (we also tried using the online pid tuner)

Vary Kp (Kp is increased from 0)keeping KI and KD constant (both are kept zeros). We tried with step size 0.1 and step size 0.01 and 1
After a reasonable oscillation has occurred (i.e. until the output of the control loop oscillates, in this case in **Gazebo**) and say, KP has stabilisation, we start increasing the KI term to stop the oscillations due to Kp. While doing this, Kp is set at the obtained value. The integral term is varied to achieve a minimal steady state error.

Then keeping Kp and Ki at their obtained values, we obtained a Kd. This is done by increasing Kd until the loop is acceptably quick to its set point.

We used these parameters to achieve the flight and results shown.

Basically Kp makes sure the output of the system is achieved faster. The integral term reduces the steady state error, but increases overshoot. Increasing derivative term decreases overshoot and yields higher gain with stability. Increasing Kd we also noticed that it made the system sensitive to noise or external force (eg in out usage with wind, but the flight is observed to be stable with some error in tracking)

The values we obtained for position gain, velocity gain, attitude gain, angular_rate_gain are:
position_gain: {x: 5.5, y: 5.5, z: 5.5}
velocity_gain: {x: 3.2, y: 3.2, z: 3.2}
attitude_gain: {x: 1.2, y: 1.2, z: 0.1}
angular_rate_gain: {x: 0.45, y: 0.45, z: 0.07}

These gains are obtained by a trial and error method, as described above.

We wanted to use .bag data to present the evaluation of how erroneous the tracking is with wind and without wind, but we face an error over and over and we could not complete this part.

## *Note:*

***Please find Wind modelling, results and simulation video links from the ppt (submitted along with the report)***

***Please find the link for the videos shown in evaluation here***
***1.mkv -> final simulation with wind***
***2.mkv -> final simulation without wind (so we can compare the trajectory tracking between both the cases)***
https://drive.google.com/drive/folders/1ikZXQLy3Jy2mHqT39jXujk9MYM2O331O?usp=sharing

## References:


[1] https://www.powervision.me/en/product/powereggx/specs
[2] https://www.swellpro.com/waterproof-splash-drone.html#specs
[3] https://www.propelleraero.com/blog/the-pocket-guide-to-winter-drone-surveying/
[4] https://www.dji.com/mavic-2/info#specs
[5] https://github.com/ethz-asl/rotors_simulator
[6] https://www.ros.org/