Semester Report
2020/21 Second Semester

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Title of the dissertation: Design and Realization of an Autonomous Soaring Robot Using Real-Time Information from Wild Birds and Realistic, Data-Driven Model of Atmospheric Convective Updrafts

1 Introduction

Thermal soaring is a form of flight where objects gain altitude using thermals (localised updrafts) reducing the need for powered flight (e.g. wing flapping). Some soaring birds solve this challenge efficiently by flying as a flock. The main goal of this project is two-fold: to understand the properties of the thermals these birds fly in and to unravel the rules of collective thermalling they fly by. Over the course of this and the previous semester, I have tackled the first of these objectives: data-driven modelling of thermals using the high-resolution GPS tracks from soaring birds. These GPS velocities (velocity relative to the ground) are assumed to be the sum of two components: the velocity of the air relative to the ground and the velocity of the bird relative to the air. The goal of this task is, therefore, to make this decomposition and extract the air velocity. However, we don't have a ground-truth dataset to assess the validity of the decomposition. So I have resorted to synthetic data where each component is known and summed onto synthetic GPS data.

Over the course of this semester, I have address the issues pointed out on the previous report. On the side of synthetic data generation, synthetic birds now present a non-circular (less stereotypical) motion leading to a better coverage of the thermal. Air velocity fields was made more versatile, opening the possibility for more complex (more realistic) air motion. On the decomposition side, horizontal components of the air velocity is also being estimated, and wind estimation yields better results. A visualization tool was developed to allow an "holistic" view of the results. I shall present these three developments separately in the following sections.

2 Synthetic Dataset

The synthetic data are being generated from the ground up: determine the bird velocity and air velocity separately, sum them and integrate. I shall detail these two components separately below.

2.1 Air Velocity

Currently the air velocity field can be generated with the same three components as mention in last report: wind, thermal profile and thermal rotation. However each of these components can be generated with a much larger flexibility. Each component can be defined as a generic function of time and space or set with data by means of local interpolations. See Fig. 1 for an example.

2.2 Bird Velocity

The motion of synthetic birds is now calculated from the second law of mechanics (under the assumption of steady flight): the forces - lift, drag, weight are calculated as functions of the 6 degrees of freedom of a rigid body and parameters specific to each individual, such as mass, wing area, lift and drag coefficient. With this setup each bird can have different parameters and the bank angle can be set by a control algorithm.

The control algorithm determines the value of the bank angle the bird will fly at each instant. This update is constrained to a maximum absolute values of the bank angle and its variation over time. These values can also be different for each individual introducing variability in the flock. The thermal core estimate was introduced as an auxiliary variable calculated at every instant and defined as the average position of the last N circles weighed by the vertical ground velocity.

The algorithm is divided into two phases: exploration and exploitation. During the exploration phase, the bird will try to find a region of good lift by leveling the flight when better lift is found (Reichmann rules). Once the exploration phase is over, the exploitation phase begins. Its goal is to keep the bird in vicinity of the estimated thermal core. This way the bird will remain in a region of good lift over the course of the whole circle. This comprises two competing contributions: one try to keep the bird circling around the thermal core estimate at that altitude and another tries to level the flight when better lift is found. See Fig. 2. It's important to note that synthetic birds are generated one by one and, therefore, there is no synchronization or collaboration between them. This will be part of later stages in this

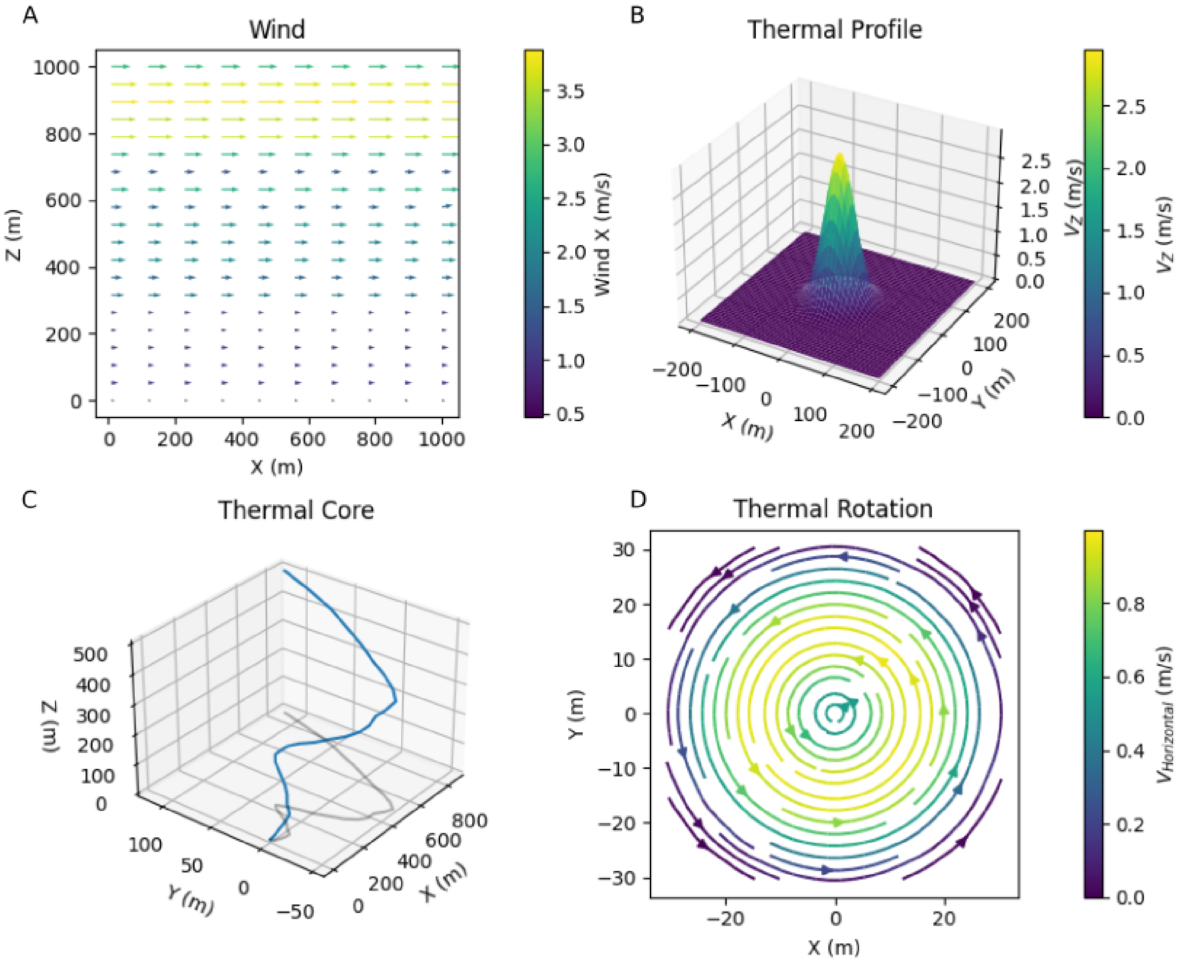

Figure 1: Synthetic air velocity field - (A) data-driven wind along the X direction on earth-fixed coordinate system. This velocity field is the result of mean field of 2 m/s summed with random walk noise. A similar situation along the y direction. (B) Thermal profile on the thermal coordinate system defined as a gaussian distribution A=3 and σ=30. (C) Resulting thermal core on earth-fixed coordinate system. (D) Thermal rotation on the thermal coordinate system defined as $V_\theta = A\rho(R-\rho)$ where ρ is the distance to the thermal core and R is a parameter $R = 30m$.

doctoral project.

3 Decomposition Algorithm

The decomposition of horizontal components of the air velocity were introduced in a similar fashion to the vertical component detailed in the previous report: change of frame of reference, bin averages of horizontal components and flight dynamics The wind velocity is now estimated using the estimate for the thermal core which present good agreement with the ”real” data. This assumes that the inclination of thermal core is only due to presence of wind.

4 Visualization

Since we are trying to extract several components from one source of data - the three components of the GPS velocity - all these components will be couple together: changes in one will influence the remaining. It was therefore necessary to develop a visualization tool to observe the all components simultaneously. Moreover, since these components evolve in space (and in time, in near future), it was necessary to make this tool interactive in order to analyse specific region. See Fig. 3.

5 Future Directions

Currently it is possible to generate synthetic birds with different physical as well as behavioural (control) parameters. The decomposition algorithm, however, assumes only one set of parameters and it not being optimized at the moment.

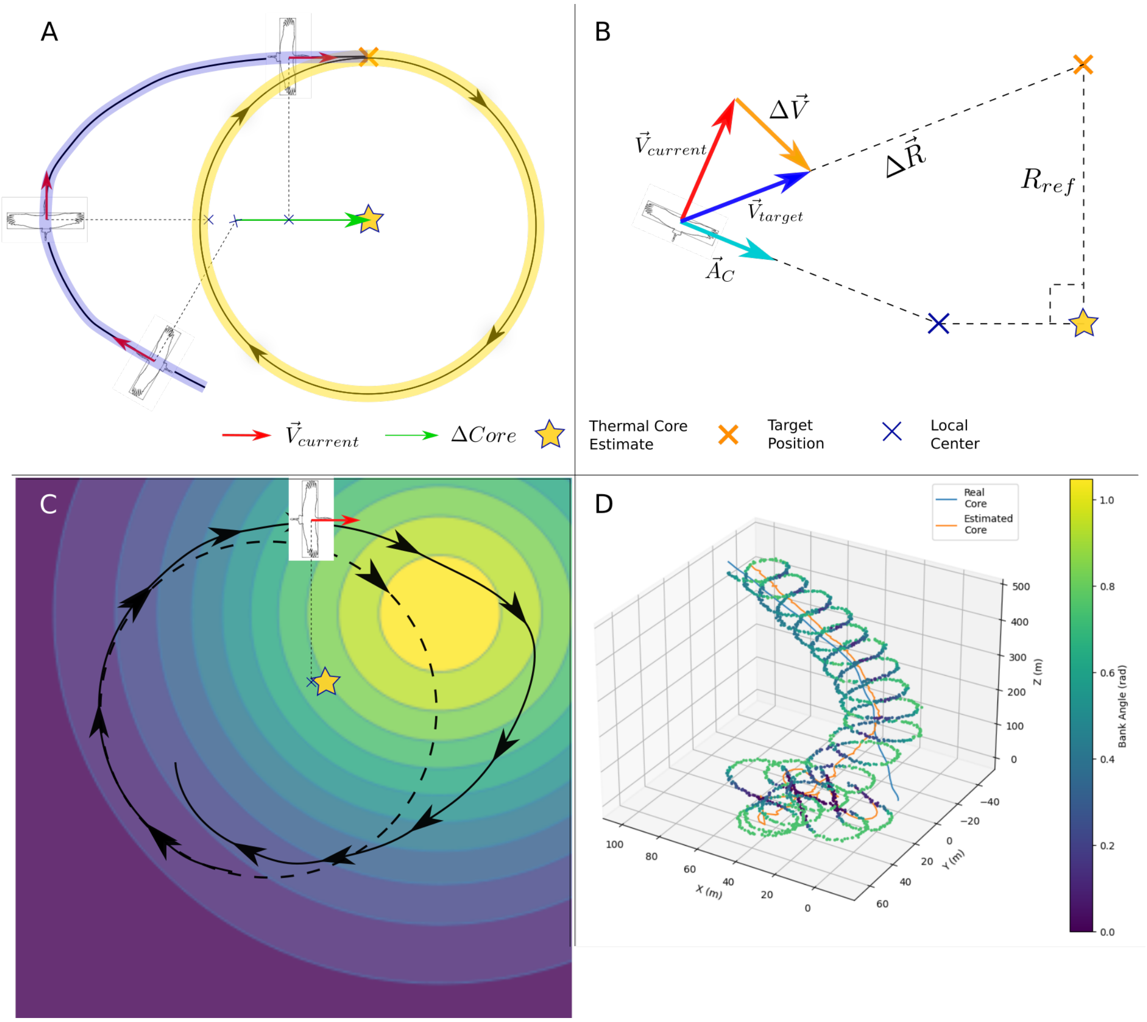

Figure 2: Exploitation phase of control - This phase is separated into two phases: Approach and Thermalling. (A) Overview of the exploration phase of the control: The approach (in blue) and the thermalling (in yellow) (B) Approach phase: it tries to place the bird on the target position (prescribed with a reference radius R_{ref}) in a greedy - not optimal - fashion prior to initiating the thermalling phase. At each instant it greedily tries to adjust the bank angle such that $\vec{V}_{current}$ aligns with $\Delta\vec{R}$ (C) Thermalling phase - it comprises two competing contributions: one (dashed line) that tries to keep the center of the trajectory (black cross) on the thermal core estimate (yellow star) and another (solid line) that employs Reichmann rules. On the background one can see an illustration of the lift, where yellow represents large values and purple small values. (D) An example of this control mechanism on a non-uniform wind velocity field. On the lowest part of the trajectory one can see the exploration part with the characteristic 8-figure trajectory and then the more regular exploitation phase.

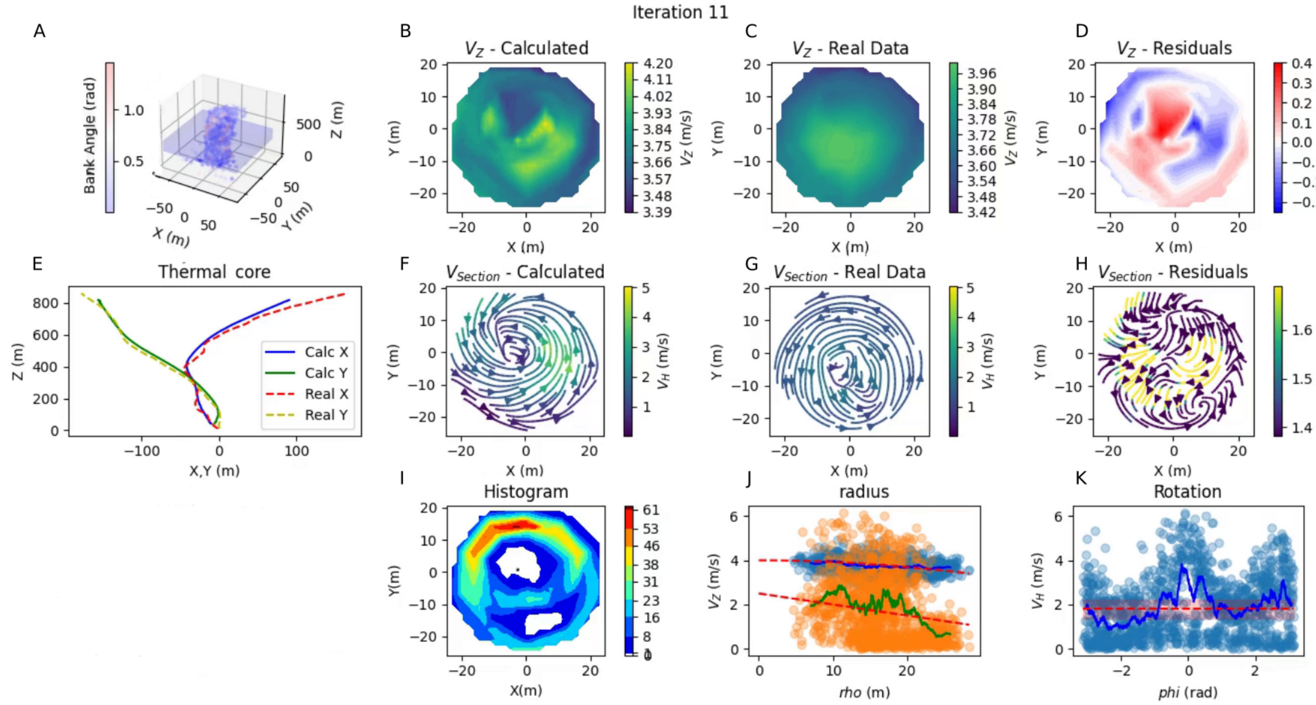

Figure 3: Interactive Visualization Tool - In this figure one can see several plots resulting from the decomposition after 11 iterations. Here "Real Data" refers to the synthetic ground truth data. A Gaussian with maximum value of 4 m/s and a $\sigma = 100m$ was utilized as thermal profile (vertical speed), and a linearly descending function of the axial distance as a thermal rotation. (A) Birds' positions after alignment (drifting caused by the horizontal wind was eliminated). (B) Calculated vertical air velocity with linear interpolation. (C) Ground-truth vertical air velocity. (D) Difference between Ground-truth vertical air velocity and calculated vertical air velocity. (E) Calculated X and Y positions of the thermal core along the Z direction as the thermal itself and as a consequence the birds' trajectories are drifting with the horizontal wind. (F) Calculated horizontal air velocity with linear interpolation. (G) Ground-truth horizontal air velocity. (H) Difference between Ground-truth horizontal air velocity and calculated horizontal air velocity. (I) Histogram of the birds position in the thermal's frame of reference. (J) Vertical velocity (blue points) and horizontal velocity (orange points) along the axial direction in the thermal's frame of reference along with the moving averages (blue line and green line, respectively). The dashed lines correspond to the averages of the ground truth data. (K) Horizontal velocity as a function of the azimuth in the thermal's frame of reference along with the moving average (blue line). The dashed line represents the average of the ground truth data.

Iterating these parameters will be the principal focus of my research in the next semester: first iterating for a single set of parameters - assuming all birds are equal - and then iterating as many set of parameters as there are birds in the thermal. Currently the control algorithm cannot react to when a synthetic bird "loses" the thermal. This is an important aspect that should be corrected because on the real data it is observed that soaring birds do lose the thermal. Moreover, updraft are known to be surrounded by downdraft which should also be part of the thermal model we are trying to achieve. It is, in fact, something that all previous works on autonomous thermalling control have disregarded. On the decomposition part, bin to bin correlations should be introduced. This will ensure that quantities such as mass and moment are conserved and will make the air flow smooth.

6 Studies

During this semester I was enrolled in the "Advanced Statistics and Modelling" (FIZ/3/088) class taught by Dr. Farkas Illés József, Dr. Oroszlány László, Prof. Kaufmann Zoltán, Prof. Palla Gergely and Prof. Pollner Péter, and "Data Exploration and Visualisation" (FIZ/3/085) class taught by Dr. Ágnes Becsei, Dr. Krisztián Papp, István Márkusz, Dr. József Stéger and Prof. Dávid Visontai to strengthen my understanding of modelling and visualization techniques.

7 Professional Activities

During the course of this semester, I became the administrator of two servers of MTA-ELTE research groups hosted by the Department of Biological Physics.