Semester Report
2020/21 First 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

Over the course of this semester, I've started the first planned task on this doctoral project: data-driven modelling thermals using the high-resolution GPS tracks from soaring birds. I am assuming that the GPS velocity (velocity relative to the ground) is the sum of two components: one component is the velocity of the air relative to the ground and the other is the velocity of the bird relative to the air. The goal of this task is, therefore, determining the air velocity. However, each individual component is unknown making it impossible to determine the validity of the decomposition. To address this issue, I have resorted to synthetic data where each component is known. I shall describe the synthetic data generation and then the algorithm that is being developed to separate the above mentioned components.

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

The air velocity field is parameterized by the (horizontal) wind, thermal profile and thermal rotation as functions of the space coordinates and time. First the thermal core is calculated: it establishes, for a given altitude Z, the X and Y coordinates around which the thermal profile and rotation are calculated. At each time step, given a bird's position, the wind, thermal vertical velocity and thermal rotation are summed and the three components of the (local) air velocity is determined. At present, this summation is not taking into account laws of fluid mechanics, e.g., the continuity equation. See Fig 1 for an example cross section of the air velocity field, where a constant wind and Gaussian thermal profile were used.

2.2 Bird Velocity

Each bird is assumed to be in steady flight at all times. In this quasi-stationary framing, there are three forces acting on the bird (lift, drag and weight) whose sum vanishes when the bird is not turning. The bird, however, is allowed to turn producing an horizontal, inwards components of the lift, which is balanced by the centrifugal force, and, hence, the total forces remains zero. The bird turns by means of the roll motion (defined by its bank angle) which determines its turning radius as well as its velocity. These forces are determined by parameters - lift coefficient, drag coefficient, weight and wing area - that are specific to each bird.
After the bird parameters and initial conditions are determined, the track of each bird is modelled as the

stereotypical spiral, where the bank angle is determined, at each time step, as a random variable sampled around an average value.

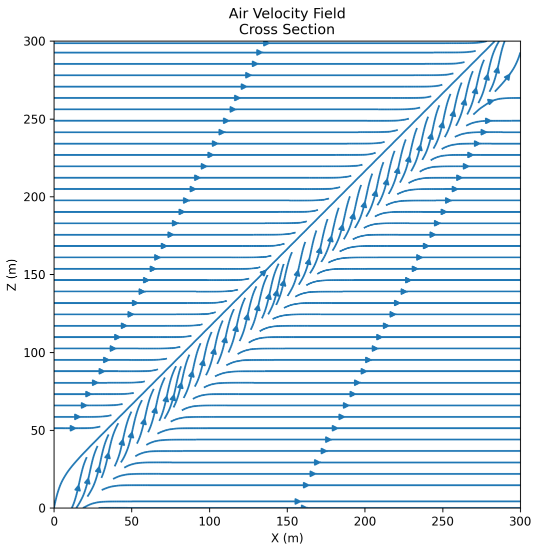

Figure 1: Cross section of the air velocity field generated using horizontal wind along the X-direction and Gaussian thermal profile.

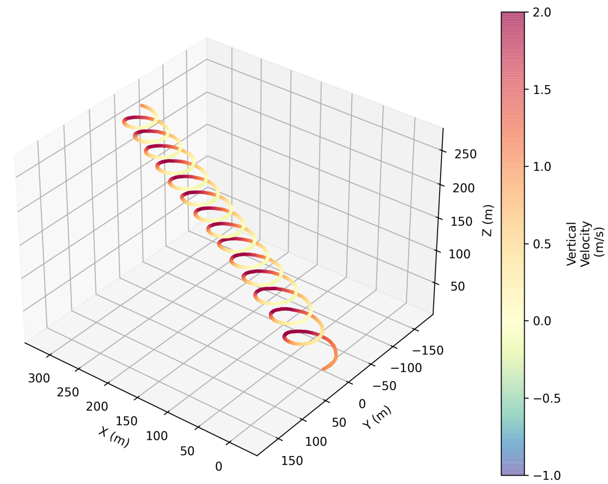

Figure 2: Synthetic GPS track generated in the air velocity field in Fig. 1

2.3 Composition

Finally the air velocity and bird velocity are summed and integrated. Synthetic Gaussian noise can be added to simulate real instrumentation noise. See Fig. 2, for an example where only one bird is plotted for sake of clarity. The final dataset includes many birds in the air velocity field. It includes the separated velocities as well as all intermediate parameters (such as radius or bank angle).

3 Decomposition Algorithm

As mentioned above, the goal of this task is to determine the air velocity field from the soaring birds' GPS tracks. At present, this algorithm assumes the GPS velocity (velocity relative to the ground) as the sum of the air velocity and the bird velocity, that each bird is in steady flight at all times, the air velocity does not change over time, and that all birds have the same parameters.

In each iteration, the first step is determining the thermal core by means of an average position weighted with the vertical air velocity determined in the previous iteration. This allows the calculation of the wind velocity and the change of variables where the thermal is vertical (see Fig. 3). In this frame of reference, one can calculate geometric features of the bird trajectory such as the local turning radius and it is possible to apply steady flight rules and determine a new iteration of the bird velocity and consequently the air velocity.

In Fig. 4 the results of the decomposition after 28 iterations are presented. In this example, 24 synthetic birds were generated in an air velocity field with a Gaussian thermal profile with constant wind and constant thermal rotation. On the top left panel, the calculated vertical air velocity is plotted using a nearest-neighbor interpolation to fill empty bins. On the top right, the residuals calculated per bin: difference between the top left and bottom left plots.

So far, this algorithm was used with the same bird parameters as the data was generated with. As of right now, the rules for iterating these parameters are being investigated. Over the course of these tasks many tools were developed for data preprocessing, analysis and visualization.

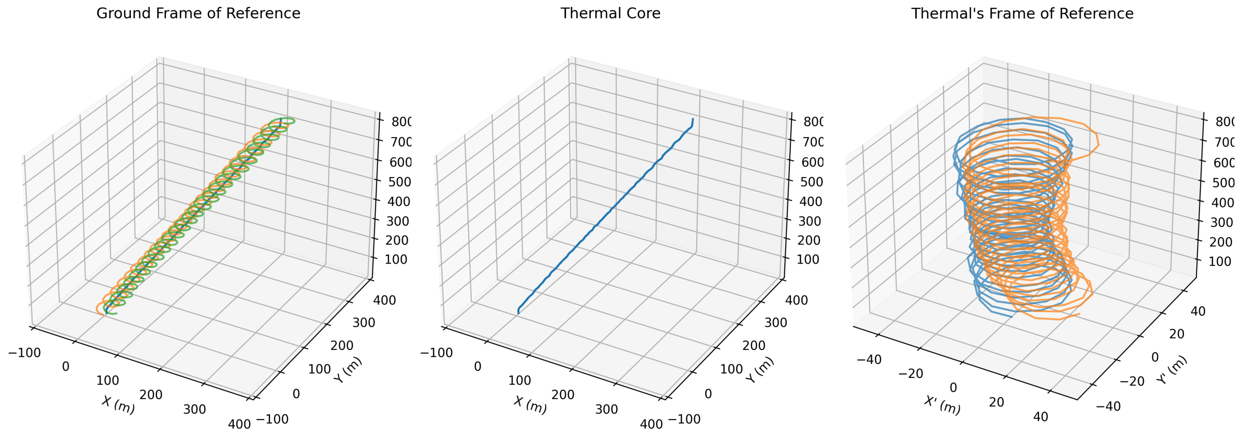

Figure 3: On the left: Example of synthetic bird trajectories on the Ground Frame of Reference. On the center: calculated thermal core. On the right: the resulting trajectories in the local coordinate system, that is center at every altitude to the core of the estimated thermal.

4 Future Directions

On the side of synthetic data, I plan to improve both the bird velocity and the air velocity. As the initial step, the birds movement in the air were generated as "simple" circling without any adjustment to the thermal, or more preciously downward spiraling in the air irrespective of what net vertical velocities this produces. The resulting synthetic data was found to lead to biased trajectories: most synthetic bird trajectories are found upwind of the thermal core. This behaviour is not observed in the real bird data: we observe relatively homogeneous vertical speed distribution that could indicate that soaring birds tend to optimize their trajectory to stay close to the strongest updraft. Furthermore, this bias leads to systematic offset in the calculated thermal core and consequently in calculated thermal profile. A control mechanism is going to be developed to make synthetic bird trajectories more similar to real bird trajectories. The air model utilized in the synthetic data is going to be improved with the introduction of a turbulence model and dependence in time.

On the side of the decomposition algorithm, the rules for iterating bird parameters are being investigated, as of right now. I plan to allow different birds to have different parameters and iterate these parameters. Relaxing the assumption that the air velocity is constant in time will also be dealt with in the near future.

5 Studies

During this semester I was enrolled in the "Data Mining and Machine Learning" (FIZ/3/084) class taught by Biricz András Mátyás, Dr. Csabai István, Olar Alex and Pataki Bálint Ármin, and "Physics of Environmental Flows" (FIZ/3/017E) class taught by Dr. Jánosi Imre Miklós, Dr. Tél Tamás and Dr. Vincze Miklós Pál to strengthen my understanding of modelling techniques and atmospheric phenomena.

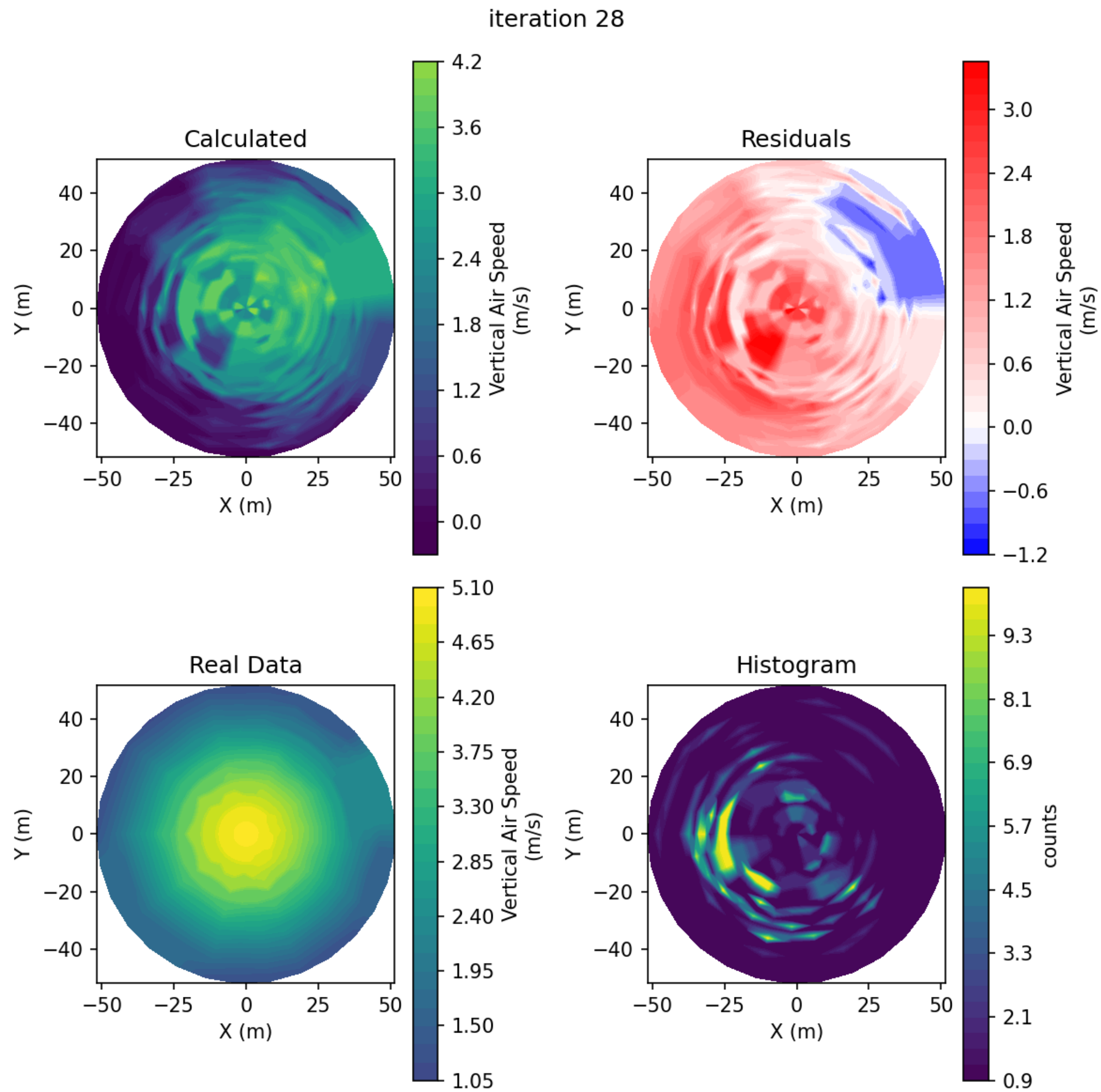

Figure 4: Results of the decomposition algorithm after 28 iterations as top view contour plots. Top left: calculated vertical air velocity, interpolated with nearest-neighbour interpolation. Bottom left: thermal profile using upon generating the synthetic data. Top right: difference between Real Data and Calculated data. Bottom right: Occupation of each bin.