Toward Computing an Optimal Trajectory for an Environment-Oriented Unmanned Aerial Vehicle (UAV)

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Need for Unmanned . . .
Need for Easily . . .
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Towards an Optimal . . .
An (Almost) Optimal . . .
Minor Problem
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What If We Want . . .
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Implementation Is . . .
Tailwind Problem. I. . . .
Missed Spot Problem. . . .

1. Need for Unmanned Aerial Vehicles (UAV)

- Arctic observing systems need to be enhanced with improved remote sensing technologies and capabilities.
- Especially needed are mid-altitude remote sensing using air-borne platforms.
- Over the past decade a few but increasing number of researchers have begun using UAVs in the Arctic.
- Typically UAVs tend to be designed for a specific task or area of operation.
- Thus, UASs are usually not easily customizable.
- Our objective: develop easily customizable UAVs.

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2. Need for Easily Customizable Unmanned Aerial Vehicles (UAV)

- *Our objective:* develop UAVs that allow for:
  - customizable sensor packages,
  - reliable communications between ground and aircraft,
  - tools to optimize flight control,
  - real time data processing,
  - the ability to visually ascertaining the quantity of data while the UAV is air-borne, and
  - the ability to launch and land safely in these remote regions.
- *We present:* a prototype software system that allows for this customization.

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3. Technical Details of Our System

- *A paraglider UAV* allows low and slow flying with up to 13 kg payload.
- *A suite of sensors* for measuring hyperspectral reflectance and other surface properties.
- *Onboard sensors* relay airspeed, ground speed, latitude, longitude, pitch, yaw, roll, and video.
- *Additional sensors* can be added.
- *Software:*
  - has enhanced communication ground $\leftrightarrow$ UAV;
  - can synthesize near real time data acquired from sensors onboard;
  - can log operation data during flights;
  - can visually demonstrate the amount/quality of data.

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4. Need for an Optimal Trajectory

- *Task:* cover all the points points from a given area.
- *Problem:* UAVs have limited flight time.
- *Consequence:* minimize the flight time among all covering trajectories.
- *Geometric reformulation:* we need a trajectories with the smallest possible length.
- *Usual assumptions:*
  - we cover a rectangular area;
  - each on-board sensor covers all the points within a given radius r.
- *What we do:* describe the trajectories which are (asymptotically) optimal under these assumptions.

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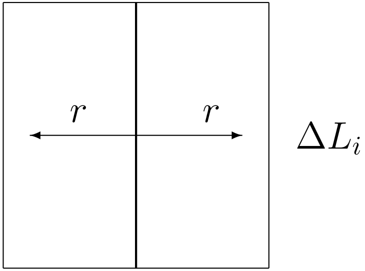
5. Towards an Optimal Trajectory

- Each trajectory piece of length ΔL_i covers the area $A_i \approx 2r \cdot \Delta L_i$:



- So, a trajectory of length $L = \sum_i \Delta L_i$ covers the area

$$A \le \sum_i A_i = \sum_i (2r \cdot \Delta L_i) = 2r \cdot \sum_i \Delta L_i = 2r \cdot L.$$

- *Conclusion:* to cover a region of area A_0, we need a trajectory of length $L \ge \dfrac{A_0}{2r}$.

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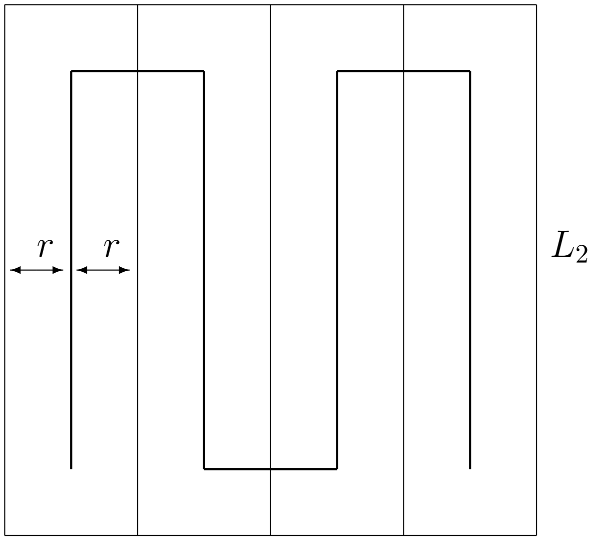
6. An (Almost) Optimal Trajectory



- In the region of area $A_0 = L_1 \cdot L_2$, we have $\dfrac{L_1}{2r}$ pieces of length $\approx L_2$ each.
- The total length is $L \approx \dfrac{L_1}{2r} \cdot L_2 = \dfrac{L_1 \cdot L_2}{2r} = \dfrac{A_0}{2r}$, i.e., this trajectory is (almost) optimal.

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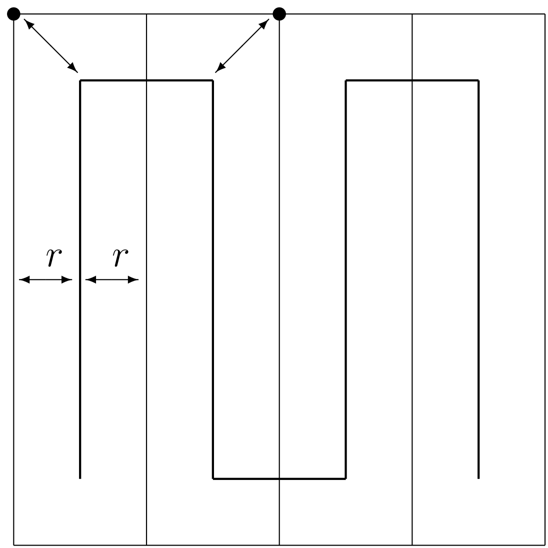
7. Minor Problem



- *Problem:* corner points (marked bold) are not covered.
- *Explanation:* the distance from the trajectory to each corner point is $\sqrt{r^2 + r^2} = \sqrt{2} \cdot r > r$.

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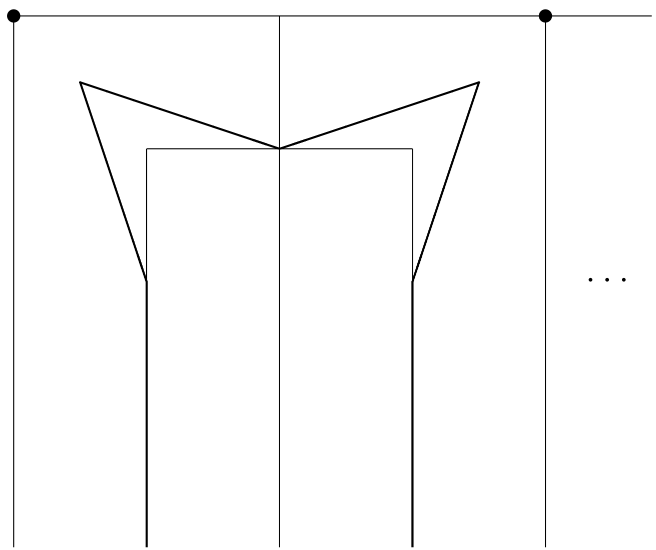
8. Solution: How to Cover Corner Points



- *Comment:* this way, corner points are covered.

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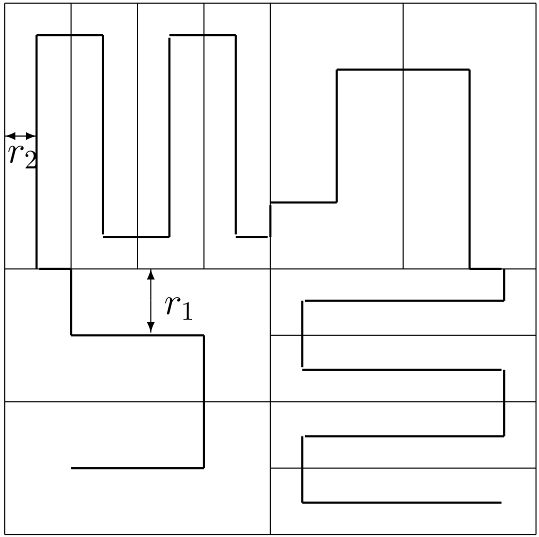
9. What If We Want Different Coverage In Different Sub-Regions: Asymptotically Optimal Solution



- *Idea:* use (asymptotically optimal) arrangement in each sub-region; this sub-division can be iterated.

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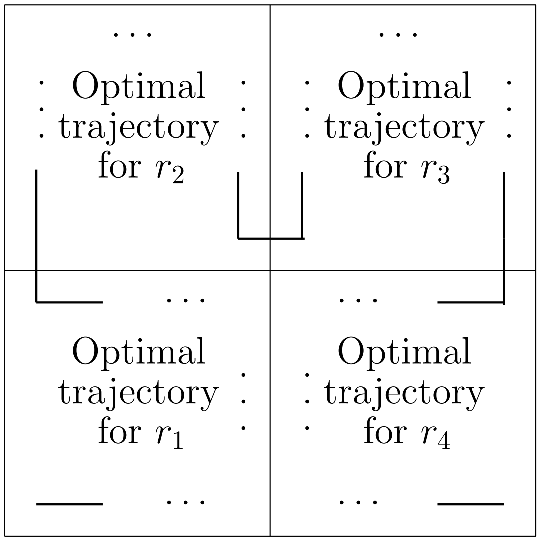
10. What If We Want Different Coverage In Different Sub-Regions: General Case



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11. Implementation Is Imperfect: Additional Problems

- *In practice:* an UAV can deviate from the planned trajectory.
- *As a result:* we may not cover some points in the region.
- *First example:* tailwind.
- *Why it is a problem:* the UAV flies too fast, not enough time for sensing.
- *Solution:* change the direction of the trajectory.
- *Second example:* missing one spot.
- *Possible explanation:* a sensor malfunctioned.
- *Solution:* come back and cover the missed spot.
- *Question:* what is the optimal way to cover the missed spot?

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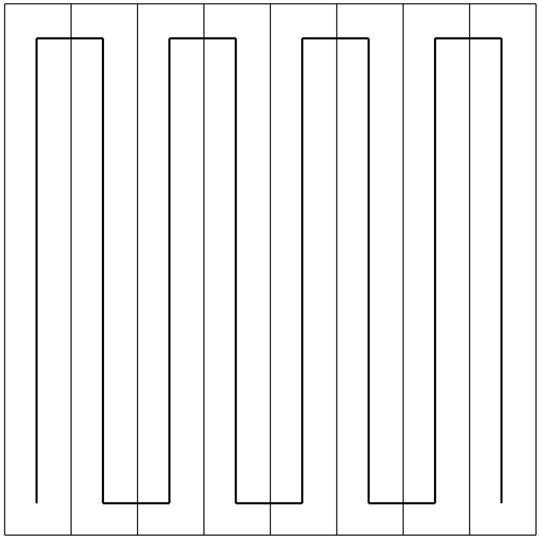
12. Tailwind Problem. I. Original Plan



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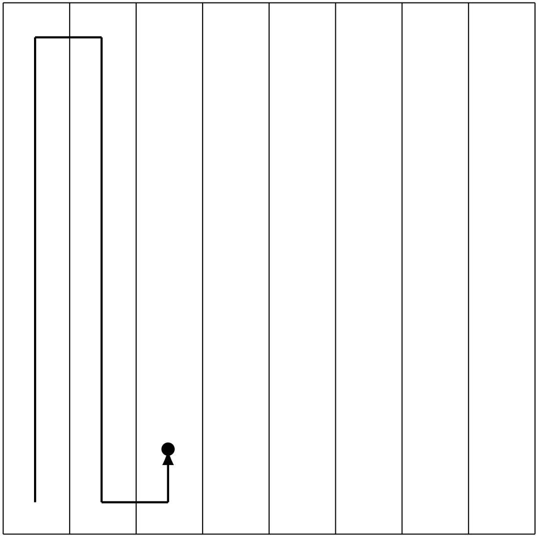
13. Tailwind Problem. II. Plan Disrupted by Tailwind



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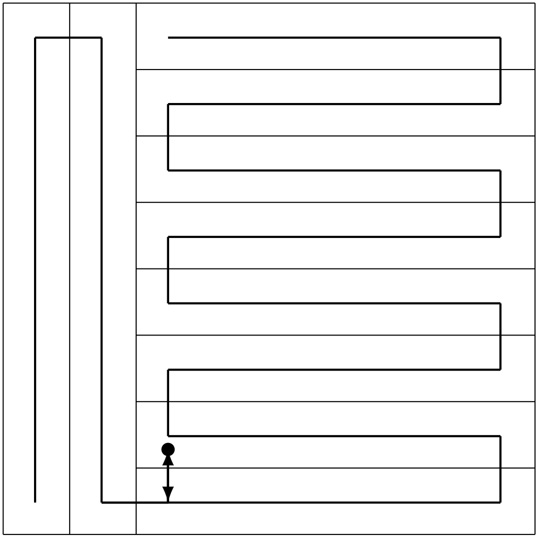
14. Tailwind Problem. III. Solution: Change Direction



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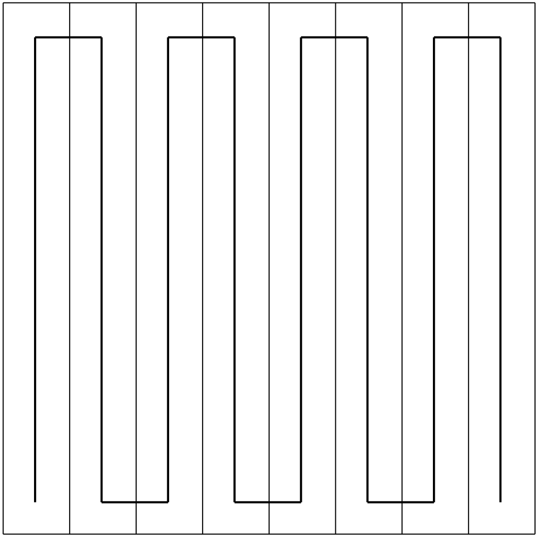
15. Missed Spot Problem. I. Original Plan



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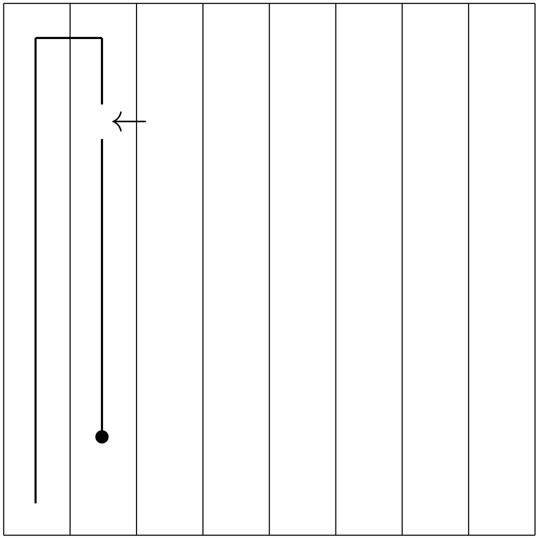
16. Missed Spot Problem. II. Plan Disrupted



- *Problem:* by the time we learn about the disruption, the plane has moved along the planned trajectory.

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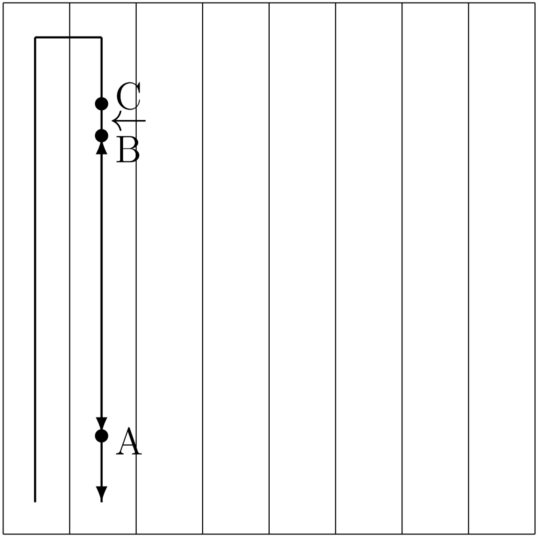
17. Missed Spot Problem. III. Seemingly Natural Idea: Come Back, then Continue



- *Problem:* we waste time by covering AB 3 times: original path, going back, and resuming the path.

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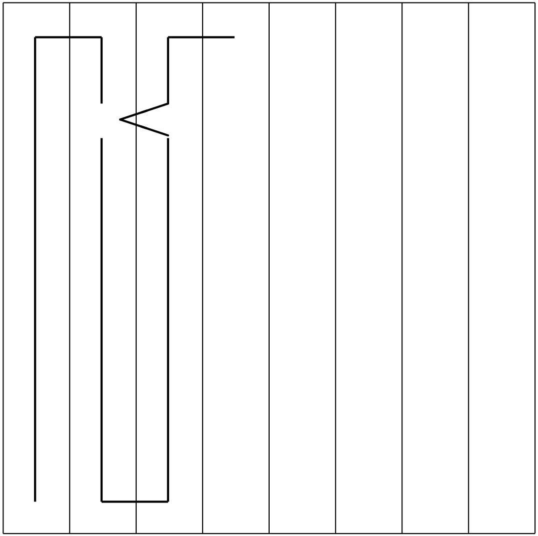
18. Missed Spot Problem. IV. Better Idea: Repair the Spot on the Next Iteration



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19. Acknowledgments

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  - Cyber-ShARE Center of Excellence (HRD-0734825),
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