Final Project Proposal: Geo-Referencing From Camera-Pose and Digital Elevation Model Information

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1. Project Motivation:

In many real-world settings, we capture images with cameras that already provide rich metadata: GPS location, altitude, focal length, and sometimes orientation. At the same time, high-resolution Digital Elevation Models (DEMs) of terrain are widely available. This project is motivated by the question: Given what we already know about the camera and the surrounding terrain, how much can we infer about the world coordinates of features visible in a single image?

By combining camera metadata with terrain information, it should be possible to transform image measurements (pixels) into physically meaningful geographic estimates. The goal of this project is to explore how scene knowledge (DEMs) and camera knowledge together reduce ambiguity in monocular images and enable reliable geolocation terrain features.

2. Project Goals

The goal of this project is to build a minimal end-to-end system that can geolocate terrain features in a single outdoor photograph using only the camera's GPS position and a digital elevation model. The project will implement a simple method to estimate camera orientation by aligning an extracted skyline with a synthetic DEM-derived skyline, and will use a basic pixel–to–ray intersection procedure to project selected image points onto the terrain surface. The final objective is to demonstrate this lightweight pipeline on a small set of geo-tagged images and qualitatively assess the accuracy of the resulting geolocated terrain points.

3. Related Work:

- **A New Monoplotting Tool to Extract Georeferenced Vector Data and Orthorectified Raster Data from Oblique Non-Metric Photographs**: Presents a user-friendly monoplotting system that georeferences single oblique photographs using DEM–ray intersection and control-point–based camera calibration to generate orthorectified raster and vector data [1].
- **Georeferencing Oblique Aerial Wildfire Photographs: An Untapped Source of Fire Behaviour Data**: Demonstrates that monoplotting operational wildfire photographs yields sub-meter fire-front localization and accurate rate-of-spread estimates [2].
- **HORAYZON v1.2**: Introduces a ray-tracing system that computes horizons and sky-view factors with performance gains over conventional DEM methods [3].

4. Milestones:

- **[Done] Select a Small Set of Test Images:** Choose 2–3 geo-tagged photographs with clear ridgelines from Washington, West Virginia, and Alaska, each containing GPS position, focal length, and image dimensions (but unknown heading).
- **[Done] Acquire Required DEM Tiles:** Download only the minimal DEM tiles covering each camera location (USGS 1/3 arc-second ∼10–30m data and ArcticDEM < 5m where available) and preprocess them into a simple height grid.
- **Implement a Minimal Camera Model:** Construct a pinhole projection model using focal length and sensor size, ignoring lens distortion and using a coarse grid-search over yaw (and optionally roll) to align the photo skyline to the DEM skyline.
- **Extract a Skyline Curve:** Apply a edge detector (e.g., Canny) and select the uppermost strong edge in each column to obtain a crude skyline silhouette without semantic segmentation.
- **Photo-to-DEM Alignment:** Render a synthetic DEM skyline from the known camera position for multiple yaw values, compute a simple correlation score between extracted and synthetic skylines, and choose the best-appearing alignment.
- **Ray-DEM Intersection:** For a small number of manually selected ridge pixels, cast rays into the DEM and find their intersection using a simple incremental stepping algorithm to recover approximate 3D coordinates.
- **Produce Final Visualizations and Error Discussion:** Plot the input image with selected pixels, the corresponding ray-intersection points on the DEM, and provide qualitative accuracy observations (no full uncertainty analysis required).

References

[1] C. Bozzini, M. Conedera, and P. Krebs, "A new monoplotting tool to extract georeferenced vector data and orthorectified raster data from oblique non-metric photographs," *International Journal of Heritage in the Digital Era*, vol. 1, no. 3, pp. 499–518, 2012.

[2] H. Hart, D. D. B. Perrakis, S. W. Taylor, C. Bone, and C. Bozzini, "Georeferencing oblique aerial wildfire photographs: An untapped source of fire behaviour data," *Fire*, vol. 4, no. 81, 2021. DOI: `10.3390/fire4040081`.

[3] C. R. Steger, B. Steger, and C. Schär, "HORAYZON v1.2: An efficient and flexible ray-tracing algorithm to compute horizon and sky view factor," *Geoscientific Model Development*, vol. 15, pp. 6817–6840, 2022. DOI: `10.5194/gmd-15-6817-2022`.