Bounded-error victim localization
for UAV-based search and rescue operations

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Keywords: Localization, Drone, Search and Rescue, Vision, Digital Elevation Model, Intervals

Introduction

Small unmanned aerial vehicles (UAVs), are currently used by firefighters teams for search and rescue operations, leveraging the use of thermal imaging and zoom cameras for finding and identifying lost people. The victim is detected and tracked in the image, but the rescue team on the ground needs georeferenced coordinates to intervene. The classical operational way is to describe the victims position relative to surrounding landmarks, and to fly the drone above the victim to take down its geographical coordinates (latitude and longitude).

UAVs are equipped with GPS and inertial navigation systems, which enables to know their position and orientation in a geographical reference frame. Assuming that the onboard camera calibration parameters are known, it is possible to cast each image measurement into a *ray* in the real world. Locating a victim can thus be done either by intersecting the rays obtained from two different views, or by intersecting the ray from a single observation with the ground surface obtained from a digital elevation model (DEM).

Interval methods have successfully been used for vision-based localization [2] or reconstruction [3], and also for DEM-aided positioning [1]. Assuming uncertain camera calibration and drone pose (position and orientation), this work aims to compute a bounding domain of the possible position of a victim localized in the drone image. Localization from a single measurement is enabled by using a DEM, whose accuracy is also taken into account.

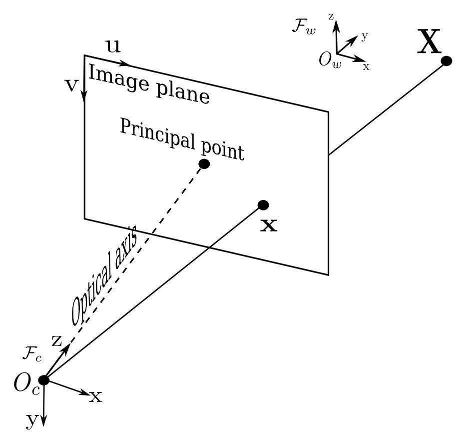

Figure 1: Pinhole camera model

Camera measurement

Image observations are described by the pinhole camera model (Fig. 1). A point in the image plane corresponds to a ray in the world. The camera ray uncertainty can be divided into two components: origin and direction.

A first source of ray direction error is expressed in the camera image plane (in pixels). It is related to pointing/tracking accuracy. The camera intrinsic parameters ma-

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trix $\boldsymbol{K}$ (obtained from calibration) enables to relate the measured image plane coordinates $\bar{\boldsymbol{x}} = (u, v, 1)^T$ to the ray coordinates $\boldsymbol{x} = (x, y, 1)^T$ in the normalized space:

$$\boldsymbol{x} = \boldsymbol{K}^{-1}\bar{\boldsymbol{x}}, \ \boldsymbol{K} = \begin{pmatrix} p_x & 0 & u_0 \\ 0 & p_y & v_0 \\ 0 & 0 & 1 \end{pmatrix}$$

The second source of ray direction error is the camera orientation ${}^c\boldsymbol{q}$ in the global frame. The pitch and roll components of the error are generally small (a few tenths of a degree if the camera gimbal is well calibrated and the drone is not accelerating). The yaw component can be subject to larger errors (in the order of a few degrees), since it is estimated by a magnetic compass onboard the drone.

The ray origin corresponds to the camera position ${}^c\boldsymbol{p}$, measured by the GPS of the UAV. The width of the position error domain can vary from several meters if using standalone GPS, to tenths of centimeters if using differential techniques (DGPS, RTK).

The constraint from a single image observation defines a domain corresponding to the "uncertain direction ray" (cone) originating from the camera center, and dilated by the uncertainty box of the GPS position. The set of 3-D world points ${}^w\boldsymbol{X}$ compatible with the image observation is given by:

$$\mathbb{S}_{\text{camera}} = \{{}^w\boldsymbol{X} \mid \bar{\boldsymbol{x}} = \boldsymbol{K}\,\boldsymbol{\Pi}\;{}^c\boldsymbol{T}_w({}^c\boldsymbol{p}, {}^c\boldsymbol{q})\,{}^w\boldsymbol{X}, \\ \bar{\boldsymbol{x}} \in ([u], [v])^T,\ {}^c\boldsymbol{p} \in [{}^c\boldsymbol{p}],\ {}^c\boldsymbol{q} \in [{}^c\boldsymbol{q}]\}$$

where ${}^c\boldsymbol{T}_w$ is the rigid transform from the world reference frame to the camera frame, and $\boldsymbol{\Pi}$ is the perspective projection. The intervals $[u], [v]$ represent bounded-error measurements in the image plane. The boxes $[{}^c\boldsymbol{p}]$ and $[{}^c\boldsymbol{q}]$ are respectively the position and orientation uncertainty domains of the camera.

Digital elevation model

The digital elevation model provides a useful additional constraint for locating people, assuming they are on the ground. A DEM is classically a regular grid of altitudes. The accuracy of the terrain model has to be taken into account, since it can greatly vary depending on the data source. Particularly, DEM precision tends to be worse in mountain areas, which is where most of the SAR operations occur. The DEM precision is described by two components: altimetric accuracy and planimetric accuracy.

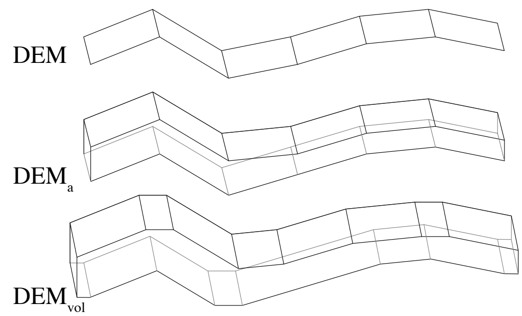

Figure 2: "Thick DEM" construction

From the ground surface defined by the DEM mesh, we define a "thick DEM" as the domain of the possible locations of the ground surface, taking accuracy figures into account. Thickening the DEM is done in two steps (Fig. 2). Firstly, the punctual altitude measurements are converted to intervals accordingly to altimetric accuracy. This leads to a first volume DEM_a. Then, we compute the Minkowski sum of the obtained domain DEM_a with a square $[\pm e_x; \pm e_y; 0]$ representing the planimetric accuracy, to obtain the final "thick DEM" DEM_{vol}.

Victim localization

Assuming bounded errors, the DEM and the image tracking measurements define sets that are guaranteed to contain the victim's position. A bounding domain of the victim's position can thus be obtained by intersecting the "thick DEM" with the "uncertain rays" corresponding to each visual observation.

References

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