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Vision-based target geo-location using a multirotor vehicle

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Abstract. This paper presents a method for determining the GPS location of a ground-based object when imaged from a multirotor vehicle. Using the pixel location of the target in image, with measurement of multirotor position and attitude, and camera pose angles, the target is localized in world coordinates. The localization method has been implement and flight tested on a multirotor vehicle and experimental results are presented demonstrating the localization of a target to within range from 2-15 meters of its known GPS location.

1. Introduction

One of the primary reasons for the current interest in small unmanned aircraft is that they offer an inexpensive platform to carry electro-optical (EO) and infrared (IR) cameras. Almost all small and miniature air vehicles that are currently deployed carry either and EO or IR camera. While the camera is primarily used to relay information to a user, it makes sense to attempt to also use the camera for the purpose of navigation, guidance, control, and accurately determine the location of ground-based objects.

This paper presents a method for determining the location of objects in world/inertial coordinates using a gimballed EO/IR camera on-board a multirotor UAV. We have assumed that the target is identified in the video stream by a human end user. The target is then automatically tracked at frame rate using a combination of colour segmentation and feature tracking [1]. After the object has been identified in the video stream and an initial estimate of its world coordinates. However, the geo-location results presented in [2] are often in error by more than 20 meters, while our method achieves localization errors below 15 meters.

The remainder of the paper is organized as follows. In Section 2, we present the concept of a geolocation. In Section 3 and Section 4 we present the basic mathematics used to obtain the raw target localization estimates from a single frame within the video. We present flight results demonstrating the effectiveness of our method in Section 5, and offer some concluding remarks in Section 6.

2. The concept of a geolocation

The task of geolocation targets from airborne video is required for many application in surveillance, law enforcement, reconnaissance, etc. The usual approaches to target geolocation involve terrain data, single target tracking, gimbal control of camera head, altimeter, etc.

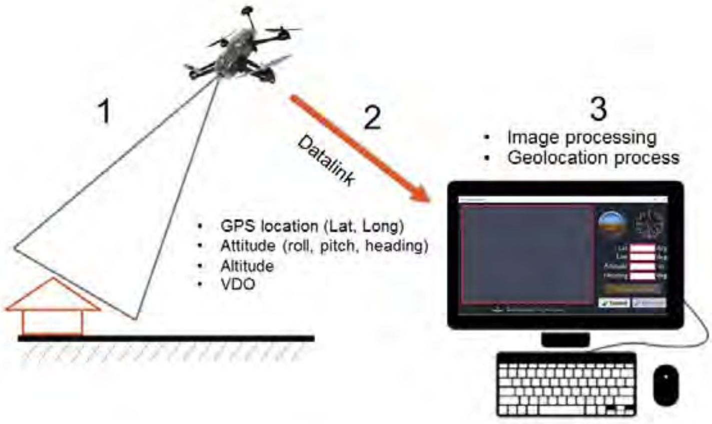

Figure 1. The concept of vision-based geolocation for a multirotor UAV.

In figure 1 shows concept of vision-based geolocation for a multirotor UAV, an airborne video are transmitted by video downlink at 5.8 GHz to ground PC, while flight data are transmitted by XBee-pro at 900 MHz to ground PC in the same time. After that the ground PC are estimated the position of ground-based target by geolocation equation.

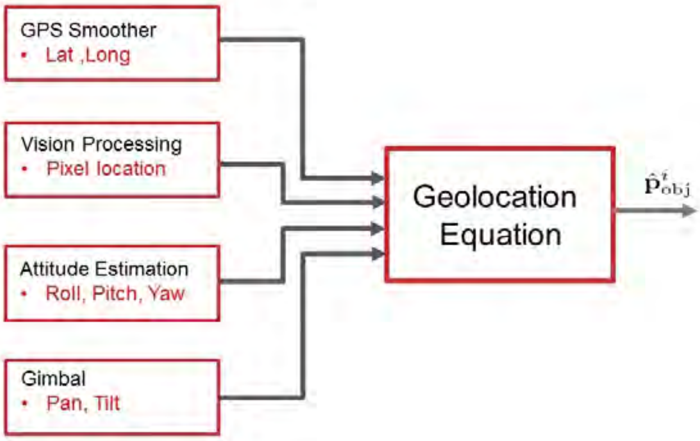

Figure 2. The geolocation algorithm.

A block diagram of the geolocation algorithm is shown in figure 2. The input to the geolocation algorithm is the position and velocity of the UAV in the inertial frame as estimated by the GPS smoother, the estimate of the normalized line-of-sight vector, and the estimate of the attitude of UAV.

3. Target Localization

To estimate the 3D coordinates of ground target [3], target position is computed by intersecting the ray starting from the camera center and passing through the target pixel location in the image plane with the ground. In this section, the method are described for locating the stationary target in the navigation coordinate system. In order to achieve this objective, relation between coordinate frame information is described briefly as follows:

3.1. Coordinate Frames and Conversion

The Localization algorithm uses a number of coordinate frames and considers transformations of 3-vectors among coordinate frames. We assume that all coordinate frames are right-handed and orthogonal.

3.2. **The inertial coordinate Frame (I)** is an earth-fixed coordinate system with its origin at the defined home location. This coordinate system is sometimes referred to as a north-east-down (NED) reference frame. It is common for north to be referred to as the inertial x direction, east to be referred to as the inertial y direction, and down to be referred to as the inertial z direction. The transformation from vehicle frame to body frame is given by:

$$R_v^I = \begin{bmatrix} -x_{uav} \\ -y_{uav} \\ h_{uav} \end{bmatrix} \tag{1}$$

3.3. **The vehicle frame (v)** is at the center of mass of the UAV. However, the axes of v are aligned with the axis of the inertial frame, in other word the x direction points north, y direction points east, and z points toward the center of the earth.

3.4. **The body frame (b)** is vehicle-carried and is directly defined on the body of the flying vehicle. Its origin is the center of mass, x direction points out the nose of the airframe, y direction points out the right wing, and z direction points out the belly. The transformation from vehicle frame to body frame is given by

$$R_v^b = \begin{bmatrix} c_\theta c_\psi & c_\theta s_\psi & -s_\theta \\ s_\phi s_\theta c_\psi - c_\phi s_\psi & s_\phi s_\theta s_\psi - c_\phi c_\psi & c_\theta s_\psi \\ c_\phi s_\theta c_\psi + s_\phi s_\psi & c_\phi s_\theta c_\psi - s_\phi c_\psi & c_\phi c_\theta \end{bmatrix} \tag{2}$$

where, $c_\phi = \cos\phi$ and $s_\phi = \sin\phi$. The angles ϕ , θ, and ψ are commonly referred to as Euler angles. Euler angles are commonly used because they provide an intuitive means for representing the orientation of a body in three dimensions.

3.5. **The sensor frame (s) -** The origin of the S frame is at the optical center of the camera with geodetic coordinates. The z axis is along the general downward direction along the optical axis. The x axis is to the right hand side of the image .The y axis completes the right-handed coordinate frame. The image points and normalized image points are expressed in the S frame (u_x, v_x, f) .

$$F = \sqrt{v_x^2 + u_y^2 + f^2}$$
$$l^s = \frac{L}{F}\begin{bmatrix} u_x \\ v_y \\ f \end{bmatrix} \tag{3}$$

where $l =$ the vector to the object of interest and $L = \| l \|$.

4. Geolocation

This section presents a method for determining the location of objects in world/inertial coordinates using a video camera on board a multirotor UAV.

$$p_{obj}^I = P_{uav}^I + L(R_v^I R_b^v R_s^b l^s)$$
$$p_{uav}^I = (p_n, p_e, p_d)^T \tag{4}$$

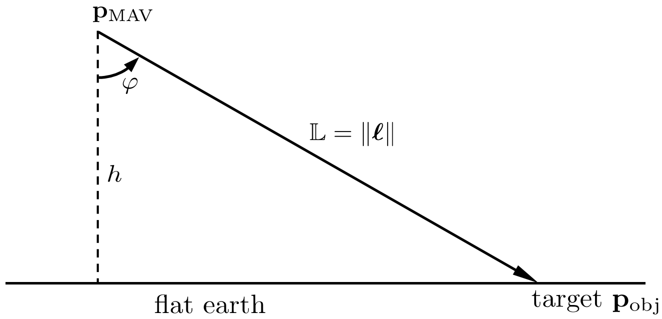

Figure 3. Range estimation using the flat-earth assumption.

The only element on the right-hand side of equation 4, which is unknown is L . Therefore, solving the geolocation problem reduces to the problem of estimating the range to the target L . If digital elevation model is not available, simple strategy for estimating L is to assume a flat-earth model. Figure 3 shows the geometry of the situation where $h = -p_d$ is the height-above-ground, and φ is the angle between l and direction in k_i axis. It is clear from figure 3 that

$$L = \frac{h}{\cos\varphi} \tag{5}$$

Where

$$\cos\varphi = k^i l^i = k^i R_v^I R_b^v R_s^b l^s \tag{6}$$

Therefore, the range estimate using the flat-earth model is given by

$$L = \frac{h}{k^i . R_v^I R_b^v R_s^b l^s} \tag{7}$$

The Geolocation estimation is given by combining equation 4 and 7 to obtain

$$p_{obj}^I = p_{uav}^I + h \frac{R_v^I R_b^v R_s^b l^s}{k^i R_v^I R_b^v R_s^b l^s} \tag{8}$$

5. EXPERIMENTAL RESULTS

We applied a commercial multirotor UAV platform for evaluation of proposed method. The custom design of the multirotor allows us to mount all the necessary devices needed to perform target geo-location. The platform is equipped with small video camera and with appropriate sensors and autopilot to perform stabilized and autonomous flights. The autopilot unit includes MEMS gyroscopes and accelerometers, a 3-axis magnetic sensor, a barometric pressure sensor and a single frequency low-cost GPS receiver.

We develop own geolocation programming using for estimates the position of ground-based target using C++ language and Opencv is shown in figure 4. In the flight test a multirotor UAV is hover above the ground at the height of 50 meters, tracking a ground-based target, and record position of ground-based target data.

Figure 4. Shows the graphical user interface of geolocation.

The error of the raw estimates of geolocation of the target are shown in figure 5. The raw estimates have errors that range from 2-15 meters, which are compared between the raw estimates of geolocation of the target with the target location in google map.

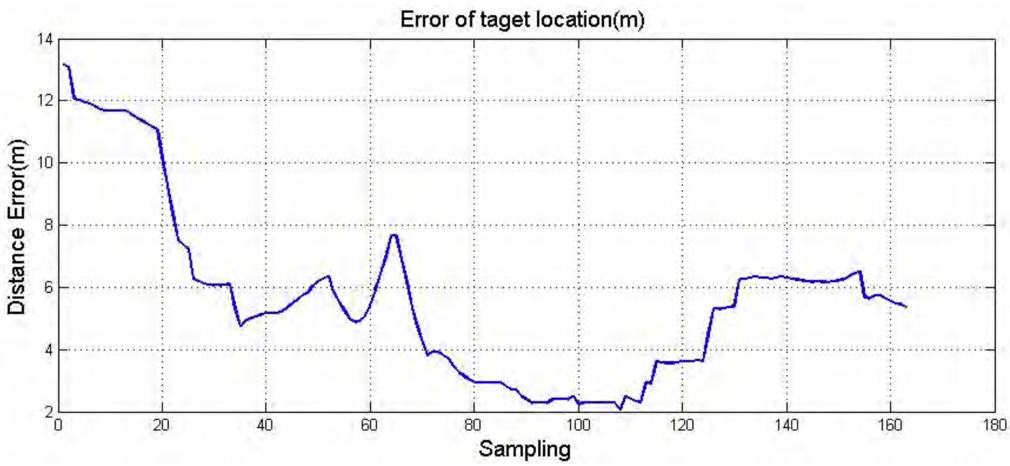

Figure 5. Shows the error of localization of a target.

Conclusion

In this paper, an algorithm capable of estimating target geolocation based on video imagery acquired by small UAV equipped with GPS. The geometry required to produce raw localization estimates is discussed in detail. Our experiments proved both the efficiency and accuracy of the position estimation algorithm by flight test in real-time. The geo-location error from flight test below 15 meters. Throughout the paper we have assumed a flat earth model and stationary target. Future research will include kalman filter to reduce the geo-location error.

References

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