INSTATANEOUS GEO-LOCATION OF MULTIPLE TARGETS FROM MONOCULAR AIRBORNE VIDEO

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Abstract

We propose a robust and accurate method for multi-target geo-localization from airborne video. The difference between our approach and other approaches in the literature is fourfold: 1) it does not require gimbal control of the camera or any particular path planning control for the UAV; 2) it does not rely on GIS information, or otherwise any geo-referenced terrain database, elevation map, or accurate altimeter for estimating the UAV's and target's altitudes; 3) it can instantaneously geo-locate multiple targets even if they were not previously observed by the camera (e.g. with a click of a mouse on the selected target); and 4) it requires only one camera, and it employs a virtual-stereo technique using the image sequence for increasing accuracy in target estimation.

The only requirements for our approach are: that the intrinsic parameters of the camera be known; that the UAV be equipped with GPS and IMU; and that other objects on ground be approximately at the same height as the target. Since the first two requirements are easily satisfied, the only real constraint is regarding the surrounding background. This constraint is necessary because our algorithm relies on various feature points from such background in order to more accurately estimate the altitude of the UAV. However, as we will explain later, this last constraint can also be alleviated if enough feature points can be extracted from the close surroundings of the target.

The result is a method that can reach a few meters of accuracy for an UAV flying at a few hundred feet above the ground. Such performance is demonstrated by computer simulation, in-scale data using a model city, and real airborne video with ground truth.

Introduction

Current research on target geo-location using passive sensors has achieved remarkable results [1, 2, 3, 4, 5, 6, 7]. In some cases, the uncertainty in the estimation is under 10 meters, with the UAV flying at an altitude of a few hundred meters. Unfortunately, these same achievements have been possible only by imposing some severe constraints to the systems. In [6, 7], for example, the proposed system could track a moving target on the ground while controlling the vehicle and its gimbal camera. At the same time, the system could estimate the target geo-location within just 5m, when flying at an altitude of over 300m. However, such results were possible only if the velocity of the target – magnitude and heading – was constant. Also, in order to estimate the target altitude accurately, the system had to rely on an equally accurate geo-referenced terrain database – e.g. PVNT [??].

In another system found in the literature, [1], the authors proposed the use of a Recursive Least Squares filter to reduce the error in geo-location. However, this type of filter imposes an even stronger constraint on the target, which had to remain stationary. Still, in the same work, the authors provided a quite useful analysis of the error, they determined its main sources and presented a study on the sensitivity and propagation of uncertainties in their method. Despite that, the errors reported were still quite large – 15m for a UAV at 60m high. Later, in a continuation of their previous work, [2], the authors extended even further their analysis of the error, they identified the sources of zero-mean noise versus constant bias, and derived an expression for the optimum altitude of the vehicle as a function of the path radius and the pixel area of the target object on the image plane. All that reduced the error to less than 10m at an optimum altitude slightly lower than 100m. However, the target still had to be stationary and the error in instantaneous estimates, i.e. without the RLS filter, could reach more than 40m, especially for non-optimum altitudes of the UAV.

In most cases, multiple frames were also required: whether they were used to estimate the target velocity [1], to reduce error using a RLS filter [2], Kalman filter [3], or to guarantee convergence and controllability of the gimbal cameras or the vehicle itself [6, 7]. In other cases, [8], even a specific path planning strategy for the UAV had to be outlined in order for the system to achieve good results.

In this work, we propose a simple, but accurate method to calculate the geo-location of multiple targets. Our method gets away with most of the above constraints, while it provides a robust instantaneous estimate of the targets geo-locations. By not employing camera

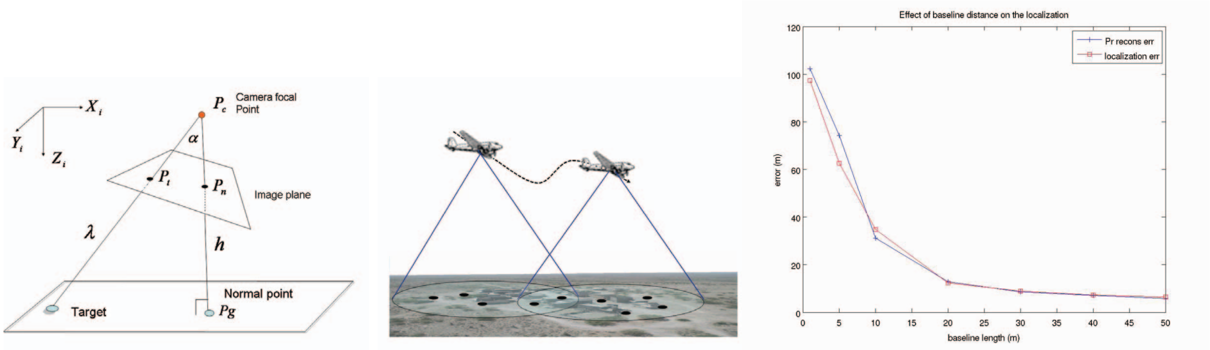

Figure 1: Estimation of (a) the target pose from a single image and (b) the altitude of the UAV from virtual-stereo images. In (c) we show the error vs. the distance between virtual-stereo images depicted in (b)

gimbal control – where only one object can occupy the center of the image – we can handle multiple targets at the same time. Also, as in [1], we provide an analysis of the error in our method and a similar discussion regarding sensibility and error propagation. Finally, to avoid the need for geo-referenced terrain databases or expensive altimeters, we propose an algorithm to estimate the altitude of the UAV based on the detection of multiple feature points around each target object.

Proposed Method

Our method can be divided into three major steps, which are executed concurrently: object tracking; target geo-location; and altitude estimation. In the first step, object tracking, multiple objects can be tracked simultaneously using a combination of differential optical flow and LKT feature tracking [??], or by simply clicking on the image of the desired target. In the second step, target geo-location, it is assumed that the altitude of the UAV with respect to the target is continuously provided by the third step of the algorithm. As in most systems today, [2, 1, 6, 7, 3], this information is required in order to calculate the distance and angle between the camera and the target. However, unlike those same systems, our method does not require the assumption of a overall flat terrain [3], a geo-registered terrain map [6, 7], or any other constraint on how the target is allowed to move [2, 1]. In the third and final step of the method, that same altitude required by the second step is actually estimated using various ground features extracted with the SIFT algorithm. Since each tracked object may be on a different ground plane, various estimates are in fact computed: each one representing the height of the camera/UVA with respect to a specific tracked object. Together with the pixel coordinates of the targets, this information is also made available to the other modules of the system. Without loss of generality, in the final paper submission we will explain our method assuming that one single object is being tracked. The extension of the method for multiple targets can be easily inferred from such explanation. As we will also explain later, the only constraint for the method to work is the existence of enough feature points around the target – i.e. on the same ground plane surrounding the target object. If that constraint is not satisfied, the system can assume that all targets are on the same plane and estimate a single altitude for all targets.

Results

The proposed algorithm has been tested for three types of data: synthetic data; in-scale data; and airborne video from UAV. As for the synthetic data, we performed a computer simulation using a typical scenario, where noise was added to all steps of the method: image processing, sensor reading, etc. Next, the algorithm was tested with real images obtained by mounting a camera onto an industrial robot arm and moving it over an in-scale model city. Finally, we tested the method using an airborne image sequence, where a GPS/IMU device was attached to the camera onboard an UAV, and another GPS device was attached to a vehicle (target) to provide ground truth for our test.

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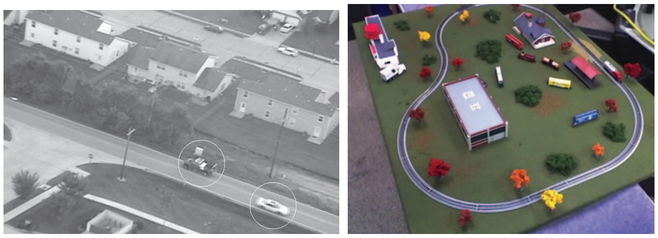

	Parameter	Uncertainty	D$_{1i}$	D$_{2i}$
1	α_{az}	.5°	0.55m	N/A
2	α_{el}	.5°	0.85m	N/A
3	yaw_{uav}	5°	4m	2.635m
4	$pitch_{uav}$	5°	5.5m	7.472m
5	$roll_{uav}$	5°	8.5m	7.228m
6	X_{uav}	5m	5m	5.016m
7	Y_{uav}	5m	5m	5.001m
8	h_{uav}	5m	6.4m	3.575m
9	u	5 pix	0.75m	0.388m
10	v	5 pix	0.95m	0.374m
11	$\sqrt{\sum (D_i)^2}$		14.9m	13.351m

Figure 2: (a) and (b) are test scenarios (UAV and model city); (c) error sensibility for the algorithm in [1], D_{1i}, and for the proposed method, D_{2i}.