Research Perspectives in UAV Visual Target Tracking in Uncertain Environments

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***Abstract*— This paper introduces our research project on vision-based UAV autonomous operation. We have developed a vision-based landing system for a UAV, and demonstrated its performance in flight last year. For more advanced study in visual navigation and guidance, we specified a mission scenario of target tracking in unknown urban environments. This paper discusses about potentials of using vision in achieving several different tasks, such as global mapping, self-localization and obstacle avoidance, in the scenario. The discussion brings out our research perspectives in this study. In addition, as a preliminary work, a new guidance law which achieves 2D vision-based target tracking while maximizing a range observability is proposed.**

I. INTRODUCTION

Vision-based navigation and guidance is one of the most focused research topics in automation of unmanned aerial vehicles (UAVs) in recent years. It is a very natural idea to use visual information for UAV autonomous operation, since birds and flying insects highly rely on their eyes to navigate themselves. We aim at developping and integrating different vision-based algorithms for robust UAV operations in unknown environments, with possible loss of GPS information for instance.

We have worked on the research project called ReSSAC, whose objective is to use a UAV for a purpose of search and rescue on unknown site. We have developed an embedded vision and decision system that automatically detects obstacles on the ground and chooses a safe place for the UAV to land by using stereo vision information[1]. Its performance was successfully demonstrated throughout actual UAV flights. Further work is still dedicated to the assessment of our vision algorithms in terms of precision and accuracy of the obstacle detection function.

After the achievement in the ReSSAC project, we proceed to a more challenging mission scenario of coordinated navigation of air and ground vehicles in an unknown urban environment. This paper first explores the potentials of using the same vision information source in order to achieve different tasks in such a mission : e.g. visual mapping, navigation and target tracking. Then a target tracking problem is more particularly addressed. It is well-known that 2D vision-based estimation performance highly depends on a relative motion of a target. Therefore, a guidance design which achieves target tracking while maximizing the estimation accuracy is proposed. The guidance performance of the proposed desgin is evaluated in simulations by comparing with performance of a nominal guidance law which is designed by ignoring the estimation error.

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II. MISSION SCENARIO AND RESEARCH PERSPECTIVES IN VISUAL TRACKING

The mission given to a UAV (or a team of multiple UAVs) is to find and track a target in an unknown urban site. Three different mission phases can be identified : global mapping, target search and target tracking. Vision information can be used for different purposes in each mission phase.

A. Global Mapping

Since the mission field is unknown, we consider to first conduct a vision-based global mapping. The UAV flies over the field at a high and safe altitude to collect images, and those images are processed to create a global map of the field. In the ReSSAC demonstrations, such a partial obstacle map was obtained online, processing the images successively gathered at different altitudes.

B. Target Search

Given the global map of the mission field, the UAV starts the target search. A realtime target detection algorithm in image processing enables the system to automatically find the target. Unlike the previous phase, a UAV should fly at a lower altitude throughout the obstacles to take a closer look at the field. Because of the UAV operation in a proximity of the obstacles, there are possibilities of GPS information loss or of encoutering unexpected obstacles. Vision information is also very useful for treating such an accidental event. In a case of loss of GPS data, the UAV can be self-localized with respect to known obstacles by using their positions appeared on images. Also, if an unexpected obstacle can be visually detected to be approaching, the UAV can take an avoiding maneuver. This problem is often called 'See & Avoid' problem. We are currently planning to apply an optical flow algorithm in a detection of approaching obstacles.

C. Target Tracking

Once the target of interest is detected, the UAV is required to follow it by maintaining a certain relative state. For a guidance purpose of target tracking, the system needs an accurately estimated relative state of the target. As stated earlier, the vision-based estimation performance highly depends on the relative motion. Therefore, in order to achieve a good tracking performance, the guidance law should be designed to satisfy the following criteria : 1) the target always stays in the camera's field of view, 2) a range observability of the vision-based estimation is guaranteed, and 3) Collision with the target and other obstacles does not occur.

In the following we focus on the third task, but this list of tasks brings out our overall research perspectives in the study of vision-based UAV autonomous operation.

III. VISUAL TARGET SEARCH AND TRACKING

As the first step towards the research goal, a new guidance desin for visual target tracking is proposed in this section. The proposed design treats the observability criterion among the three raised in Section II-C.

A. Nominal Guidance

Let $\boldsymbol{x}$ be a relative state and $\boldsymbol{a}$ be a guidance input. Suppose that the target tracking problem can be given by the following minimization problem.

$$\min_{\boldsymbol{a}} J(\boldsymbol{x}, \boldsymbol{a}) \tag{1}$$

subject to the relative motion dynamics. Suppose that this minimization problem can be solved when assuming full-state information, and let $\boldsymbol{a}^*(\boldsymbol{x})$ be the resulting optimal solution. This optimal guidance is not realizable, because the true relative state $\boldsymbol{x}$ is not available in our problem but only its vision-based estimate $\hat{\boldsymbol{x}}$ is available. In such a case, a common way to determine the guidance input is to simply replace $\boldsymbol{x}$ by $\hat{\boldsymbol{x}}$. We consider it as a nominal guidance, and denote it by $\boldsymbol{a}^0(\hat{\boldsymbol{x}}) = \boldsymbol{a}^*(\hat{\boldsymbol{x}})$.

B. New Guidance

Since the relative state estimation error is ignored in the nominal guidance, it can cause a poor guidance performance when the estimation error is large. To avoid that, we developed a new guidance design which takes account for the estimation error. Let $\boldsymbol{a}^1(\hat{\boldsymbol{x}}) = \boldsymbol{a}^0(\hat{\boldsymbol{x}}) + \Delta\boldsymbol{a}$ be the new guidance law, where $\Delta\boldsymbol{a}$ is an additional input which creates a feasible motion to the vision-based estimation. Our approach is to determine $\Delta\boldsymbol{a}$ by minimizing an expected value of the cost J defined in (1) subject to the relative navigation filter dynamics. In general, this optimization problem is highly nonlinear and hard to be solved. Hence, a suboptimal optimization technique is used to obtain $\Delta\boldsymbol{a}$[2].

C. Simulation Results

Simulation results of vision-based target search and tracking are compared between the nominal and the new guidance laws. A non-accelerating target is assumed, and an extended Kalman filter is utilized for the vision-based relative navigation in this simulation. Vehicle trajectory, true and estimated target trajectories are shown in Figure 1 (Nominal Guidance) and Figure 2 (New Guidance). When using the nominal guidance, the estimation diverged due to a loss of range observability and it resulted in the divergence in the tracking performance. On the other hand, the new guidance law created small circling motion around the target to prevent the divergence in estimation, and successfully made the UAV track the target.

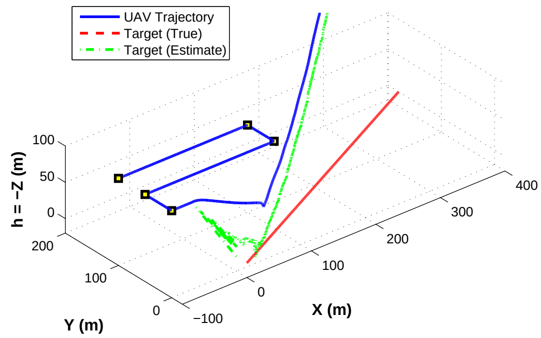

Fig. 1. UAV Trajectory, True and Estimated Target Trajectories (Nominal Guidance) : Diverence occured in the estimation and hence in the tracking.

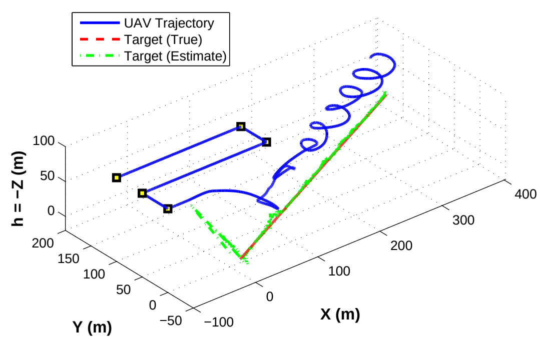

Fig. 2. UAV Trajectory, True and Estimated Target Trajectories (New Guidance) : The UAV tracks the target with small circling motion.

IV. CONCLUSIONS

This paper first defined and presented a global mission scenario and our research perspectives in the study of UAV vision-based navigation and guidance, based on our previous results of visual exploration and tracking in the ReSSAC project. As a preliminary work in our study, a visual target tracking problem was more specifically addressed and a new guidance design was proposed.

Our final research objective is to integrate different vision-based algorithms and develop the efficient and robust system for UAVs to achieve the global mission.

REFERENCES

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