The Application of Sliding Innovation Filter as Estimation Strategy Applied to a UAV

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ABSTRACT

The unmanned aerial vehicle (UAV) and unmanned aerial system (UAS) are popular in nowadays applications including military, industry, weather casting, monitoring, and many other applications. According to several research, the system must be controlled in precise way to make sure that the UAV and UAS are moving in the desired trajectories. However, this task is not an easy task in real life due to the presence of disturbances and noise in feedback measurements. To overcome this issue, researchers either developed more stable controllers, i.e. active disturbance rejection control (ADRC), or they improved the measured signals using filters with more accurate/stable performance. This work belongs to the second category, where a newly developed filter, which is referred to as sliding innovation filter (SIF), is used to estimate the states of a UAV system while it is tracking a target at the same height to improve the quality of the controller.

Keywords: Sliding innovation filter, estimation strategies, target tracking, UAV

1. INTRODUCTION

Predictor-corrector filters and observers are widely used for state and parameter estimation [1-17]. These filters can be roughly divided into two categories: those aiming for optimal solutions and those focused on maintaining stability [18-33]. One of the most recent filters in the latter category is the Sliding Innovation Filter (SIF) [34-61]. This filter shares similar principles with the Smooth Variable Structure Filter (SVSF) and sliding mode observers (SMOs) [62-85].

Unmanned air vehicles (UAVs) are extensively utilized in various applications such as military operations, agriculture, and target tracking [86-103]. There is considerable ongoing research in these areas, particularly in recent advancements. Relevant literature can be found in [104-138]. This study is a direct application focused on estimating a UAV while it targets a flying object at the same altitude level. The paper partially relies on the model derived in [139]. The SIF is employed to estimate both the target and UAV (observer) trajectories, based on data from several sensors measuring the observer's location and the target's position relative to the UAV.

The remainder of the paper is organized as follows: Section 2 provides a summary of the SIF, while Section 3 describes the model. Section 4 discusses the results, followed by the conclusion in Section 5.

2. THE SLIDING INNOVATION FILTER

The SIF algorithm can be summarized as follows [34-61, 139]:

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$$Initialize\ \hat{\mathbf{x}}_{o_{0|0}}, \hat{\mathbf{x}}_{0|0}$$
$$\hat{\mathbf{x}}_{o_{k|k-1}} = \mathbf{A}\hat{\mathbf{x}}_{o_{k-1|k-1}}$$
$$\hat{\mathbf{z}}_{o_{k|k-1}} = \hat{\mathbf{x}}_{o_{k|k-1}}$$
$$e_{z_{o_{k|k-1}}} = \mathbf{z}_{o_k} - \hat{\mathbf{z}}_{o_{k|k-1}}$$
$$\mathbf{K}_{o_k} = \left\{\begin{matrix} \left|e_{z,o_{1_{k|k-1}}}\right| / \Psi_{\mathrm{o}_1} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \left|e_{z,o_{m_{k|k-1}}}\right| / \Psi_{\mathrm{o_m}} \end{matrix}\right\},$$
$$\hat{\mathbf{x}}_{o_{k|k}} = \hat{\mathbf{x}}_{o_{k|k-1}} + \mathbf{K}_{o_k}\left(e_{z_{o_{k|k-1}}}\right)$$
Then
$$\hat{\mathbf{x}}_{k|k-1} = \mathbf{A}\hat{\mathbf{x}}_{k|k-1} + \mathbf{A}\hat{\mathbf{x}}_{o_{k-1|k-1}} - \hat{\mathbf{x}}_{o_{k|k}}$$
$$\hat{\mathbf{z}}_{k|k-1} = \left[\sqrt{\hat{x}^2_{1_{k|k-1}} + \hat{x}^2_{2_{k|k-1}}}, \tan^{-1}\left(\frac{\hat{x}_{2_{k|k-1}}}{\hat{x}_{1_{k|k-1}}}\right), \hat{x}_{3_{k|k-1}}, \hat{x}_{4_{k|k-1}}\right]^T$$
$$e_{z_{k|k-1}} = \mathbf{z}_k - \hat{\mathbf{z}}_{k|k-1}$$
$$\mathbf{K}_k = \left\{\begin{matrix} \left|e_{z,1_{k|k-1}}\right| / \Psi_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \left|e_{z,m_{k|k-1}}\right| / \Psi_{\mathrm{m}} \end{matrix}\right\},$$
$$\mathbf{H}_k = \begin{bmatrix} \frac{\hat{x}_{1_{k|k-1}}}{\sqrt{\hat{x}^2_{1_{k|k-1}} + \hat{x}^2_{2_{k|k-1}}}}, \frac{\hat{x}_{2_{k|k-1}}}{\sqrt{\hat{x}^2_{1_{k|k-1}} + \hat{x}^2_{2_{k|k-1}}}}, 0, 0 \\ \frac{-\hat{x}_{2_{k|k-1}}}{\hat{x}^2_{1_{k|k-1}} + \hat{x}^2_{2_{k|k-1}}}, \frac{\hat{x}_{1_{k|k-1}}}{\hat{x}^2_{1_{k|k-1}} + \hat{x}^2_{2_{k|k-1}}}, 0, 0 \\ 0, 0, \hat{x}_{3_{k|k-1}}, 0 \\ 0, 0, 0\ \hat{x}_{4_{k|k-1}} \end{bmatrix}$$
$$\hat{\mathbf{x}}_{k|k} = \hat{\mathbf{x}}_{k|k-1} + \mathbf{H}_k^{+}\mathbf{K}_k\left(e_{z_{k|k-1}}\right)$$
Where $\mathbf{x}$ and $\boldsymbol{z}$ are the state and measurement vectors, respectively. The numeric subscript represents the state's number, while the subscripts $k,\ k|k-1$ and $k|k$ represent the time step, the a priori estimate value, and the a posteriori value, respectively. The subscript o and t represent the observer and the target, respectively, while the vector without the letter represents the relative quantity between the observer and the target. **A, H** and **K** are the state, measurement, and correction matrices, respectively. e is the error vector, while the $\hat{a}$ is the estimate value of a. Ψ is the boundary layer vector, and it is a design factor.

3. UAV/TARGET TRACKING MODEL

The system can be summarized as follows [139]:
$$\mathbf{x}_{o_k} = \mathbf{A}\mathbf{x}_{o_{k-1}} + \mathbf{w}_{o_{k-1}}$$
$$\mathbf{x}_{t_k} = \mathbf{A}\mathbf{x}_{t_{k-1}} + \mathbf{w}_{t_{k-1}}$$
$$\mathbf{x}_k = \mathbf{x}_{t_k} - \mathbf{x}_{o_k}$$
$$\mathbf{z}_{o_k} = \mathbf{x}_{o_k} + \mathbf{v}_{o_k}$$

$$\mathbf{z}_k = \left[\sqrt{x_{1_{k|k-1}}^2 + x_{2_{k|k-1}}^2}, \tan^{-1}\left(\frac{x_{2_{k|k-1}}}{x_{1_{k|k-1}}}\right), x_{3_{k|k-1}}, x_{4_{k|k-1}}\right]^T + \mathbf{v}_k$$

Where

$$\mathbf{A} = \begin{bmatrix} 1 & 0 & dt & 0 \\ 0 & 1 & 0 & dt \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$, dt is the sampling time with a value of 1 sec.

Where $\mathbf{w}$ and $\boldsymbol{v}$ are the system and measurement noise vectors, respectively.

4. SIMULATION RESULTS

The system described in Section 3 was tested using the algorithm outlined in Section 2, and the results are depicted in Figure 1 and Table 1. The maximum absolute error (MAE) and the root mean squared error (RMSE) for the errors of x position were found to be less than 16.1 m, and less than 7.6 m, respectively.

The remaining states exhibited very small errors, with RMSE for the errors being less than 0.17 m, and for their MAE being less 0.42 m. Figure 1 illustrates the amplitude of the errors in both estimating the locations of the observer and the target. Throughout most of the simulation time, the error in both cases was less than 1%. It is noteworthy that the error in estimating the target is higher than the error in estimating the observer. This can be attributed to the fact that the error in estimating the target is accumulated from both errors in estimating the observer and inherent errors in the target's movement.

Table 1. RMSE and MAE for the results.

	$RMSE$		MAE	
	$Target$	$Observer$	$Target$	$Observer$
x	7.5137	0.0101	16.0295	0.0371
y	0.0169	0.0104	0.0400	0.0276
V_x	0.0015	0.0105	0.0041	0.0366
V_y	0.0010	0.0100	0.0028	0.0322

5. CONCLUSIONS AND FUTURE WORK

In this paper, the Sliding Innovation Filter (SIF) was employed to estimate the UAV's location while observing a target flying at the same altitude. Additionally, it estimated the target's location. The results showcase the efficiency of the SIF in a nonlinear measurement system. For future work, an experimental setup will be utilized to validate the simulated results.

Declaration

The final draft of this research paper has undergone a rigorous proofreading process, which included the utilization of advanced artificial intelligence (AI) technology.

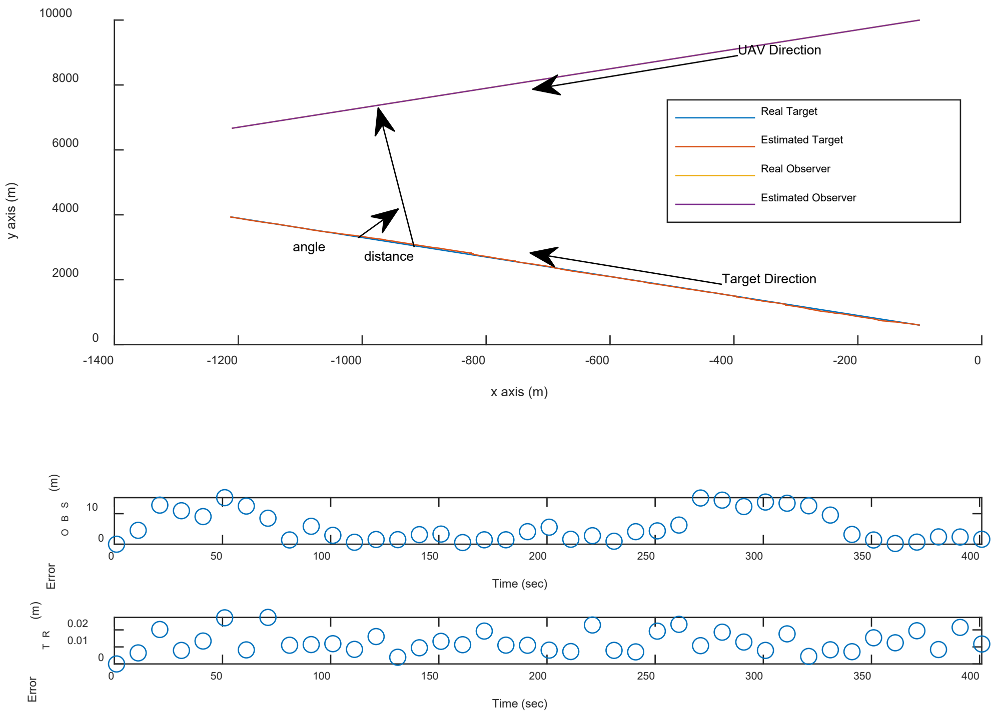

Figure 1. The trajectories of the observer and the target, and their relative errors.

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