

Localization Performance Analysis of UAV-based Integrated Sensing and Communication System

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Abstract—In integrated sensing and communication (ISAC) systems enabled by unmanned aerial vehicles (UAVs), the selection of hovering points (HPs) plays a pivotal role in determining target localization performance. This paper analyzes and compares three HP selection methods. Simulation results demonstrate that considering both range and angle can achieve accurate localization while using significantly fewer HPs. These findings highlight the importance of informative HP selection in UAV trajectory design, enabling efficient and accurate target localization with minimal sensing resources.

Index Terms—Unmanned Aerial Vehicles, Integrated Sensing And Communication, Localization

I. INTRODUCTION

Integrated Sensing and Communication (ISAC) technology that shares spectrum resources and hardware for communication and sensing (C&S) is emerging as a promising technology for sixth-generation (6G) wireless networks [1]. In particular, integrating ISAC devices onto unmanned aerial vehicles (UAVs), expands potential application scenarios and overcomes the fundamental limitations of ground-fixed base stations [2]. However, due to the limited onboard energy of UAV, the endurance and operation time are restricted. Therefore, ensuring performance with limited power is important and UAV positioning plays a critical role. Consequently, solving the trajectory and deployment problems of UAVs in UAV-based ISAC systems is a significant research area. Existing studies have aimed to achieve the performance of C&S. We focus on localization in the type of sensing performance. In [3], the authors proposed multi-stage trajectory design (MSTD) where a single-UAV provides communication and localization. In [4], trajectory planning was presented in which single-UAV visits all targets and users once to provide communication and localization.

Studies considering localization in UAV-based ISAC systems design trajectory, including hovering points (HPs) to minimize Cramér–Rao bound (CRB). Localization performance is affected by the number of HPs, the distance to the target, and the angle. While more HPs may lead to more accurate target estimation, they also increase computational complexity and

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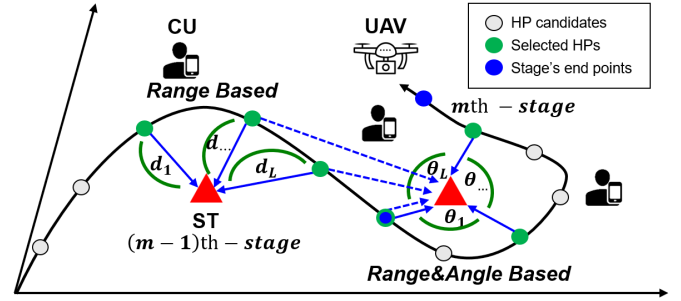


Fig. 1. System model of UAV-based ISAC.

decrease energy efficiency. Therefore, in this paper, we analyze the localization performance by considering the number of HPs as well as the distance and angle to the target. We analyze three selection methods through simulations and demonstrate the importance of selecting appropriate HPs.

II. SYTEM MODEL AND HP SELECTION

In this section, we describe the UAV-based ISAC system model and propose three methods to select HPs.

A. System Model

As illustrated in Fig. 1, we consider the UAV equipped with one transmit and one receive antenna. It serves M communication users (CUs) and localizes K sensing targets (STs). The UAV operates along the trajectory, providing communication services continuously during its flight and sensing service at HPs. The UAV trajectory consists of multi-stage. At the end of the stage, STs localization is performed, and the next stage is designed. At each stage, optimization is performed to reduce the CRB of the STs and increase the total transmit data of the CUs, considering fairness [3].

B. HP Selection Methods

The location of each ST is estimated through the maximum likelihood estimation (MLE) based on distance measurement information. For accurate target localization, HPs must be strategically selected to provide geometrically informative measurements. Let $\mathcal{Q} = \{\mathbf{q}_1, \dots, \mathbf{q}_N\}$ denote the set of accumulated HP positions, and $\mathbf{s}_k \in \mathbb{R}^2$ be the estimated

location of k -th ST ($k = 1, \dots, K$). The total number of HPs accumulated in m stages is given by $N = mN_{\text{hp}}$, where N_{hp} denotes the number of HPs per stage. We consider three different methods for selecting L HPs from the set of candidate UAV positions $\mathcal{Q}$.

1) *All HP Selection (Basic)* : The localization is performed at the end of each stage based on the HPs of all previous stages [3]. The selected set is $\mathcal{Q}_{B,k} = \mathcal{Q}$, and the number of selected points is $L = N$. This approach is simple and ensures that all available measurements are used.

2) *Range-based HP Selection (R-HS)* : Localization is performed using the L HPs closest to the estimated target position at each stage. The Euclidean distance between HP $\mathbf{q}_i$ and $\mathbf{s}_k$ is $d_{i,k} = \|\mathbf{q}_i - \mathbf{s}_k\|_2$. The selected set is

$$\mathcal{Q}_{R,k} = \arg \min_{\substack{\mathcal{S} \subset \mathcal{Q} \\ |\mathcal{S}|=L}} \sum_{\mathbf{q}_i \in \mathcal{S}} d_{i,k} \quad (1)$$

This approach prioritizes measurements from nearby points, which typically provide stronger signals and lower measurement noise.

3) *Range and Angular-based HP Selection (RA-HS)* : Localization is performed using L HPs selected from the cL closest candidates, where $c > 1$ is an oversampling factor that determines the size of the candidate set. The candidate set is $\mathcal{Q}_{\text{cand},k} = \{\mathbf{q}_i \in \mathcal{Q} \mid i \in \text{indices of } cL \text{ smallest } d_{i,k}\}$. Among these, L points are chosen to maximize angular separation. The relative angle $\theta_{i,k}$ between $\mathbf{q}_i$ and $\mathbf{s}_k$ is given by $\theta_{i,k} = \arctan 2(q_{i,y} - s_{k,y}, q_{i,x} - s_{k,x})$. The selected set is

$$\mathcal{Q}_{\text{RA},k} = \arg \max_{\substack{\mathcal{S} \subset \mathcal{Q}_{\text{cand},k} \\ |\mathcal{S}|=L}} \left(\min_{\mathbf{q}_i, \mathbf{q}_j \in \mathcal{S}, i \neq j} |\theta_{i,k} - \theta_{j,k}| \right) \quad (2)$$

This approach balances proximity and geometric diversity, which is crucial for improving the localization performance.

III. SIMULATION RESULTS

In this section, we analyze the localization performance of three different methods: *Basic*, *R-HS*, and *RA-HS*. Performance is measured in terms of root mean square error (RMSE). For simulations, the CUs and STs are randomly placed in the environment, with $M = 2$ and $K = 2$, respectively. We conducted 1,000 Monte Carlo simulations to evaluate the average localization performance.

Fig. 2 shows the performance of the *Basic* method, where the localization accuracy improves as the number of N_{hp} increases. This result confirms that utilizing more spatially distributed measurements enhances estimation performance. Nevertheless, RMSE converges as N_{hp} continues to increase, indicating diminishing returns. This trade-off highlights the importance of selecting an optimal number of N_{hp} to balance localization accuracy against sensing resource consumption.

Fig. 3 compares the performance of the *Basic*, *R-HS* and *RA-HS* methods, when the candidate set $\mathcal{Q}$ is generated with $N_{\text{hp}} = 12$ per stage. The results indicate that both *R-HS* and *RA-HS* methods achieve similar localization performance, despite using significantly fewer HPs compared to the *Basic* method.

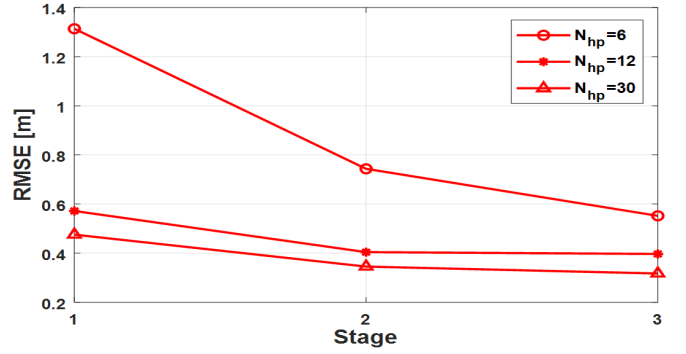


Fig. 2. RMSE of *Basic* method with different values of N_{hp} .

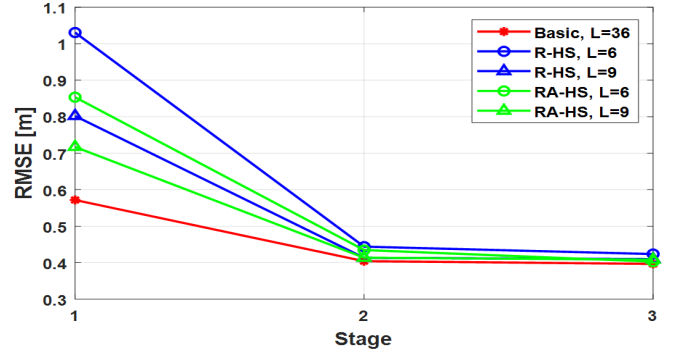


Fig. 3. RMSE of *Basic*, *R-HS* and *RA-HS* methods ($N_{\text{hp}} = 12$).

Notably, the *RA-HS* method achieves slightly better RMSE in the early stages due to the inclusion of directionally diverse measurements, but converges to similar performance as *R-HS* in later stages.

IV. CONCLUSION

In this paper, we analyze three HP selection methods for UAV-based target localization in ISAC systems. The simulation results confirmed that the method of selecting HPs has a critical impact on localization performance. In particular, appropriate selection methods can significantly reduce the number of HPs required while maintaining comparable localization accuracy. The analysis highlights the importance of selecting effective HPs by considering both distance and angular diversity. These insights can be instrumental in designing energy-efficient and accurate ISAC-enabled UAV trajectory planning frameworks.

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