

Research on Integrated Sensing and Communication Technology of Unmanned Aerial Vehicles

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Abstract: In response to the demands of 6G space-air-ground integrated networks and the development of low-altitude economy, the integrated sensing and communication (ISAC) technology for unmanned aerial vehicles (UAVs) has emerged as a novel core solution that combines wireless transmission and sensing functions. With the advantages of strong mobility and flexible deployment, UAV swarms combined with ISAC, can significantly enhance system performance. However, the ISAC for UAV swarms still faces three major challenges: difficult physical layer transmission design, difficult cooperative networking, and difficult joint scheduling of multiple tasks. To address these challenges, this paper proposes key technologies such as deep reinforcement learning, multi-sensor fusion, and parameter estimation, focusing on breakthroughs in transmission design, cooperative networking, and joint optimization of communication and sensing resources for ISAC for UAV swarms, promoting theoretical innovation and system implementation for low-altitude economy applications in the 6G era.

Keywords: Integrated sensing and communication; UAV swarms; cooperative sensing.

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1. The current situation of Integrated Sensing and Communication Technology of Unmanned Aerial Vehicles

Looking towards 2030 and beyond, human society will enter the intelligent information age. The next generation of mobile communication technology 6G, will make full use of high, medium and low spectrum resources, and integrate with advanced computing, big data, artificial intelligence, block chain and other information technologies to build an all-domain coverage network of air, space and ground, and achieve interconnection of all things, intelligent interconnection of all things, and symbiotic collaboration^[1]. In the future, higher demands for information interaction capabilities and information collection expansion functions will drive 6G air interface functions to expand from wireless transmission to wireless sensing, with sensing and communication functions overlapping in time, frequency and space, and highly coupled functions^[2-6]. This makes Integrated Sensing and Communications (ISAC) a new hot information processing technology for 6G^[7]. ISAC, based on the sharing of software and hardware resources or information, realizes the synergy and mutual benefit of sensing and communication functions, including sensory-assisted communication and communication-enhanced sensing^[8-10].

The government work report of the National Two Sessions in 2025 pointed out that efforts should be made to promote the safe and healthy development of emerging industries such as the low-altitude economy. Drones, which are highly

maneuverable and easy to dispatch, are an important part of the low-altitude economy. The coordination of multiple drone swarms can further enhance the efficiency of mission execution. They are an important platform for the realization of ISAC technology and an important part of the integrated network of air, space and ground^[11,12]. The combination of unmanned aerial vehicles (UAVs) and ISAC can effectively leverage their respective strengths. Equipping UAV nodes with ISAC integrated payloads instead of traditional discrete sensing and communication payloads can effectively reduce UAV payloads, improve UAV endurance and flexibility, that is, ISAC enhances the efficiency of UAV systems^[13]. ISAC can achieve all-round communication coverage and sensing of the environment, targets, and status, such as positioning, ranging, speed measurement, imaging, recognition, and environment reconstruction, through the flexible deployment of the unmanned aerial vehicle platform and the collaboration of multiple unmanned aerial vehicle swarm nodes, that is, UAV empower ISAC^[14-17]. UAVs naturally carry a variety of sensors such as GPS, RTK, cameras, inertial navigation devices, etc. The multi-sensory information obtained by various sensors combined with ISAC can further enhance the multi-task execution efficiency of drones, that is, sensor multi-source fusion enhances the design of the ISAC system for drones^[18].

In UAV communication-assisted sensing scenarios, target positioning, tracking, and environment imaging and reconstruction can be achieved. In sensing-assisted communication scenarios, location information-based beamforming, multi-UAV swarm networking, task scheduling, and resource allocation can be realized^[19]. Especially in the military field, future all-domain joint operations have prominent characteristics such as wide geographical range, numerous deployment points, fast combat rhythm, and complex battlefield environment. The ISAC-based UAV swarm combat platform can effectively meet the requirements of real-time battlefield situation sensing, rapid delivery of combat orders, and efficient and precise strikes, and is expected to become a disruptive force to change the rules of future battlefields.

2. Challenges of Integrated Sensing and Communication Technology of Unmanned Aerial Vehicles

As an emerging technology for the future 6G, ISAC is still in its development stage, and there are many challenges in the design of ISAC for unmanned aerial vehicle swarms. First of all, it is difficult to design the physical layer transmission of ISAC for UAV swarms. The high dynamics of ISAC for UAV swarms, as well as the differences in sensing and communication signal processing, increase the difficulty of physical layer transmission and design for ISAC for UAV swarms. New ISAC fusion modes and channel models for UAV swarm need to be designed in response to the effects of UAV motion, attitude changes, and dynamic topology of UAV swarms on sensing and communication performance. In view of the differences between ISAC sensing and communication signal processing of UAV, a joint parameter estimation method for sensing and communication needs to be designed to give full play to the multiple sensors carried by UAVs themselves and effectively utilize sensing parameter estimation to assist in the construction of communication channels and the design of transmission methods under high dynamic conditions of UAVs. At the same time, the continuous motion of unmanned aerial vehicles makes traditional signal transmission methods no longer applicable, and it is necessary to design signal transmission and beamforming methods suitable for the high dynamics of the ISAC system of UAV swarm.

Secondly, it is difficult to form a cooperative network of ISAC for UAV swarms. The dynamic topology of the drone swarm formation, the trajectory and attitude changes of the drone swarm nodes, and the occlusion effect of high-frequency transmission make the sensing and communication links of the drone swarm extremely vulnerable to interruption. It is necessary to make full use of the multi-source sensing sensors carried by the drone swarm nodes to assist in the networking design. In the ISAC scenario of the UAV swarm, it is necessary to effectively utilize the spatial gain of the large-scale antenna array of the ISAC integrated terminal and design a high-resolution angle-domain beam networking method. At the same time, the flexible deployment advantage of the drone swarm platform should be emphasized. The nodes of the drone swarm form a multi-point sensing and communication network, which can transmit ISAC signals as well as receive communication and echo signals, and the swarm can coordinate sensing and communication. In response to the impact of dynamic changes in the drone swarm on networking performance, it is necessary to integrate echo

information, channel information, and on-board sensor information, design dynamic target beam tracking and alignment methods, and comprehensively consider aspects such as the trade-off between sensing and communication signal coverage, network layer interference coordination, and the balance of system computing power and power consumption to improve networking efficiency.

Finally, the joint scheduling of multi-target sensing and multi-user communication tasks in UAV swarm is difficult. ISAC for UAV swarms involves multi-target sensing and multi-user communication. How to jointly allocate multi-target sensing and multi-user communication tasks and optimize the scheduling of limited resources of UAV swarm is a key issue that needs to be considered. In response to the sensing and communication task requirements of UAV swarm, a joint scheduling method for multi-target sensing and multi-user communication needs to be designed based on the task scenarios to achieve mutual benefit of sensing and communication functions, with a focus on the interference between multi-user communication and multi-target sensing to improve the spectral efficiency of the system. At the same time, for different ISAC mission scenarios, the planning actions and reward evaluation indicators of UAV swarm are quantitatively set to achieve efficient, robust and intelligent mission scheduling. In addition, for each mission requirement, it is necessary to establish an optimal target for ISAC resource allocation in the unmanned aerial vehicle swarm by taking into account factors such as system energy efficiency, spectral efficiency, communication transmission rate, and sensing detection accuracy. The ISAC task scheduling problem for UAV swarm is complex, involving multi-dimensional optimization variables such as system resources and UAV trajectories, and the coupling and intersection of various influencing factors increase the difficulty of joint scheduling of multi-target sensing and multi-user communication.

3. Key technologies of Integrated Sensing and Communication Technology of Unmanned Aerial Vehicles

To this end, the paper focuses on the theory and key technologies of ISAC for UAV swarms. By using theories and methods such as deep reinforcement learning, multi-sensor fusion, parameter estimation and detection, it aims to overcome difficult problems such as ISAC transmission design, cooperative networking, sensing and communication multi-task planning and resource allocation in UAV swarms.

Physical layer transport is the foundation for achieving collaborative networking of multiple unmanned aerial vehicles and joint scheduling of sensing and communication. Cooperative networking of UAV swarms is the key to achieving efficient sensing and communication within the coverage area. Joint design of sensing and communication tasks is the core for achieving multi-user communication and multi-target sensing in ISAC of UAV swarms.

4. Conclusions

UAV swarm is an important part of the future 6G space-air-ground integrated network. Studying the key technologies of integrated sensing and communication in UAV swarms can not only promote the development of ISAC theory, but also lay the foundation for the practical application of future ISAC for UAV swarms systems in the low-altitude economy.

Disclosure statement

The author declares no conflict of interest.

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