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REVIEW DEVELOPMENT STATUS AND FUTURE TRENDS OF MICRO UAVS

Introduction

The concept of micro-UAV originated from the "Micro air vehicles" program of the US Defence Advanced Research Projects Agency (DARPA). The main purpose is to develop a size less than 15 cm, with a battery life of 20 minutes to two hours. It can carry day and night cameras and is suitable for urban environments. Or drones performing activities inside buildings [1]. DARPA's definition of micro-UAVs emphasizes more on size, and there are many types of UAV classification parameters [2]. According to different masses, UAVs with a mass of 200 g to 2 kg can also be called micro-UAVs [3–4].

Micro UAVs have the characteristics of small size, light weight, good concealment and high mobility. While performing tasks such as battlefield intelligence acquisition and situational investigation, they can carry high-explosive devices for killing operations. For individual soldiers or small squads, micro-UAVs are easy to carry and have strong functions, which can significantly improve their frontier detection capabilities and close-range precision strike capabilities, improve combat efficiency and reduce casualties. In addition, micro-UAVs also have great application potential in UAV clusters and restricted space situational surveillance. For enemy targets in open areas, multiple micro-UAVs can form combat clusters in the air. Inter-ad hoc network communication to realize autonomous coordinated flight, target allocation and decision-making, air assembly and formation encirclement and other actions. For restricted spaces, such as urban environments and indoor buildings, micro-UAVs can fly slowly in narrow and complex obstacle environments due to their small size, perform regional reconnaissance, and perform intelligence acquisition or target killing tasks.

Since the development in the 1990s, research on the key technologies of micro-UAVs has emerged in an endless stream, including flight control [5–7], aerodynamic modelling [8–9], system target recognition and tracking [10–12], Autonomous navigation and path planning, system energy supply, etc., but these studies are more based on a specific technology or field, and there are relatively few articles that give a general overview of the development status of micro-UAVs, and The overview article focuses more on the introduction of micro-UAV models and detailed information, and the explanation of the key technologies of micro-UAVs is relatively simple.

The purpose of the article

On the basis of introducing the performance of micro-UAV models and sorting out the development status of micro-UAVs, this paper introduces in detail the typical research projects and research results of micro-UAVs, and aims at the miniaturization of airborne equipment of micro-UAVs, low Reynolds A summary of the technical research status is carried out in terms of digital aerodynamic design and complex environment autonomous navigation and obstacle avoidance technology. Finally, combined with the development status of micro-UAV models and technology research status, the future trends are forecasted.

Development Status of Micro UAV

1. Development Status of Micro UAV

The concept of micro-drone is based on military applications. Earlier models of micro-drone include American "MSI", "Black widow", "Nano Hummingbird" and "Black hornet". "MSI" UAV wing with a span of 15 cm and a mass of 101.5 g, it is equipped with an image sensor and can perform a flight mission of about 20 minutes. The "Black widow" UAV has a wingspan of 15 cm and a mass of 56 g. It is equipped with an ultra-light camera and can perform a reconnaissance mission for about 22 minutes. "Nano Hummingbird" is a bionic micro-UAV with a wingspan of 16 cm and a mass of 19 g. It uses a carbon fiber skeleton and flexible wings. It can flap and twist with a single power supply and has a battery life of about 10 minutes. "Black hornet" UAV The wingspan is about 12 cm, the take-off weight is 16 g, and the cruising speed is 10 m/s. It can realize real-time image and video transmission,

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and the battery life can reach 25 minutes. It is still widely used in multinational forces.

With the development of micro-nano technology and system integration technology, various types of micro-UAVs have emerged. Micro-UAVs that have appeared in recent years include the "Black hornet 3" in the United States, the "MetaFly" in France, the "Drone40" in Australia, the U.S. "RoboBee X-Wing", Israel "Ninox" series, France "ANAFI USA", UK "Bug", Belgium "Loki MK2", China "Rainbow-817" and Israel "Xtender", etc.

The "Black hornet3" UAV is a modular design, equipped with a visible light camera and a thermal imager, which can return video and image data in real time, and has all-weather situational awareness. Environment switching flight. The "MetaFly" bionic UAV has flexible wings and an elastic anti-collision design on the fuselage. It is powered by a lithium battery to drive the motor to make the wings flutter. The maximum flight speed can reach 18 km/h, which can be controlled by adjusting the tail angle. Flying and turning etc. The "Drone40" UAV has a four-rotor structure and can be thrown directly by hand or launched using a standard 40mm grenade launcher. It supports multiple load modes and can be equipped with cameras, lasers or electronic warfare interference devices to perform corresponding tasks. "RoboBee X-Wing" is an insect-like drone with a wingspan of 3.5 cm and a total weight of 259 mg. The two pairs of flapping wings are in an X layout. It can carry solar panels and use solar energy to fly. It has the ability to perform environmental monitoring tasks in narrow spaces potential. The "Ninox" series of UAVs include "Ninox40", "Ninox66" and "Ninox103". This series of UAVs adopts a foldable design and can be launched by a single soldier from a grenade launcher, tank or mobile platform, target detection and target tracking capabilities. The "ANAFI USA" UAV is a four-rotor foldable design, equipped with a high-definition camera and a thermal imager, supports encrypted data storage and transmission, is equipped with satellite navigation, inertial navigation, and air pressure sensors for flight attitude control, and has passed IP53 waterproof and dustproof certification, can fly in rainy and dusty environment. The "Bug" UAV is a four-rotor structure, equipped with high-definition cameras and thermal imaging cameras, capable of situational reconnaissance, target monitoring and target locking, and can fly in severe weather such as strong winds, rain and snow. The "Loki MK2" UAV integrates a stable flight control system, allowing the UAV to perform self-motion correction in the event of a collision, equipped with a high-sensitivity day and night camera, suitable for close-range, indoor and outdoor tactical missions. China's "Rainbow-817" micro-UAV adopts a coaxial scull design, a built-in high-capacity battery, and can be loaded with 50 g of high-energy explosives. It is a decapitating weapon suitable for attacking enemy officials. "Xtender" UAV has strong edge computing capability, combined with virtual and augmented reality technology, artificial intelligence, UAV formation and trajectory flight technology, it can realize multiple UAVs to enter the remote target site collaboratively, and complete the task without any delay. seam exit.

The detailed model information of the above domestic and foreign micro-UAVs is shown in Tab 1.

2. Typical Research Projects of Micro UAVs

In the process of the emergence of various types of micro-UAV models, the development potential of artificial intelligence and micro-UAV clusters has gradually become prominent. Some countries have begun to think about the development direction of artificial intelligence and micro-UAVs from a strategic level. The United States has successively released "UAV System Roadmap 2005–2030", "Small 2018 Ministry of National Defense Artificial Intelligence Strategy Outline" and other development planning documents guide the development of small UAVs, UAV clusters, and UAV artificial intelligence applications. Under the guidance of these planning documents, the United States has launched the "Grey Partridge" UAV swarm project, the Close Combat Covert Autonomous Disposable UAV (CICADA) project, and the Fast Lightweight Autonomous Project (FLA), etc. Carry out research on micro-UAV clusters, indoor and outdoor navigation and obstacle avoidance methods in unknown environments, and at the same time derive a series of micro-UAV products. China's research on micro-UAVs started a bit late, but there are also excellent teams such as The Fast Lab of Zhejiang University, based on five micro-UAVs, autonomous navigation in complex environments, fully autonomous UAV clusters and unmanned It has produced outstanding achievements in the industry in aspects such as mobile dynamic obstacle avoidance.

- "Perdix" drone swarm project

The "Grey Partridge" UAV is a micro-UAV developed by the Massachusetts Institute of Technology in 2011. It is made of 3D printing. It has a wingspan of 30 cm, a mass of about 0.3 kg, and a flight speed of 75-110 km/h. The battery life is about 20 minutes. After the establishment of SCO in the United States in 2012, it developed the supporting fighter air launch technology for the "Grey Partridge" UAV, and conducted multiple air launch tests based on the F-16 fighter in the "Northern Knife" military exercise in 2015. In October 2016, the U.S. military carried out an unmanned.

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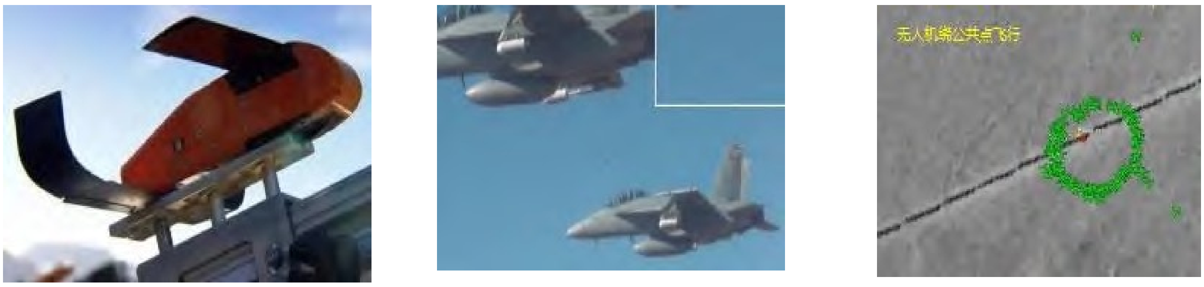
Table

Model information of several domestic and foreign micro UAVs

Numbe	Model	Time	Size /cm	Weight/g	Speed /km·h^{-1}	Load /g	Flight Duration /min
1	US "MSI"	1998	15.0	101.5	20	—	20
2	US“Black widow”	1999	15.0	56.0	40	—	22
3	US“Nano Hummingbird”	2011	16.0	19.0	17	—	10
4	US“Black hornet”	2012	12.0	16.0	36	—	25
5	US “Black hornet3”	2018	12.3	33.0	21.5	—	25
6	French “MetaFly”	2019	29.0	10.0	18	—	8
7	Australia “Drone40”	2019	18.0×18.0×4.0	190.0	72	110	30~60
8	US“RoboBee X-Wing”	2019	3.5	0.259	—	—	—
9	Israel “Ninox40”	2020	—	250.0	—	—	35
10	French “ANAFI USA”	2020	28.2×37.3×8.4	496.0	54	148	32
11	British “Bug”	2020	—	196.0	80	50	40
12	Belgium “Loki MK2”	2021	23.5×24.5×9.0	380.0	36	150	15
13	China “彩虹-817”	2021	—	850.0	64	50	15
14	Israel “Xtender”	2022	30.0×30.0×10.0	1200.0	15	150	—

The swarm ad hoc network technology test verifies that 103 "Grey Partridge" UAVs were launched by 3 F/A-18 fighters in the test. Arriving at the designated target position in the event of a collision reflects good group decision-making and group formation capabilities. "Grey Partridge" UAV and its swarm.

The flight demonstration is shown in Fig. 1.



(a) "Grey Partridge" UAV (b) warplanes release drones (c) cluster flight

Fig. 1. “Perdix” swarm flight

- Close Combat Covert Autonomous Disposable UAV Project CICADA.

The CICADA project aims to develop a single-use low-cost GPS-guided micro-drones that carry only tiny electronic devices and can be scattered in large numbers in a designated area to form a large and stable "detection matrix". The "Cicada" UAV is the hatching product of this project, as shown in Fig 2. The UAV is cheap and disposable, with a wingspan of about 12 cm and a weight of about 65

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g. It can carry miniature sensors such as air pressure, temperature and humidity for meteorological or biochemical detection. The UAV has no power equipment and relies on the gliding mechanism and GPS to fly autonomously. After reaching the target location, it can use the data link to self-organize the network to form a detection cluster.

Fig. 2. "CICADA" UAV

In April 2017, the U.S. Navy conducted a CICADA UAV launch test in which 32 CICADA UAVs could be launched from a P-3 anti-submarine reconnaissance aircraft using launch tubes, demonstrating the system's deployability on standard Navy airborne platforms. In April 2019, NASA used four large UAV Hives to launch more than 100 CICADA UAVs equipped with temperature, air pressure and wind speed sensors to form a cluster for meteorological data collection.

- Fast and Lightweight Autonomous Project FLA

DARPA's FLA project aims to develop an algorithm that integrates perception, navigation, control, and planning, enabling unmanned systems to achieve high-speed autonomous flight in unknown indoor and outdoor cluttered environments without relying on GPS or external communications. The FLA project was launched in 2015, and developed an estimator based on visual inertial ranging technology, monocular camera and inertial measurement unit, combined with near-field forward perception, multi-layer mapping and symbol perception technology, for GPS-free Precise indoor and outdoor positioning and navigation of drones; develop a trajectory planning method based on 2D global planner and 3D feedback motion primitives for high-speed obstacle avoidance flight of drones. The developed intelligent algorithm is integrated on the quadrotor UAV. The image of the UAV is shown in Fig 3. A variety of sensors are installed on the UAV to perform environmental perception tasks.

(a) FLA Drone

(b) In(out)door switching flight

Fig. 3. FLA project UAV and flight test

In 2016, DARPA carried out the flight test of this type of UAV, mainly carrying out several obstacle avoidance flight tests in different indoor and outdoor environments. In 2018, the drone's outdoor/indoor flight switching and indoor flight tasks in a narrow space were completed. During the test, the drone took off from the outside and flew in a multi-storey building. Enter the room, search and map the room in 3D, then identify and fly down the stairs, and finally fly back outside through the open door. The next step of the project is to deploy the algorithm on a smaller hardware platform, so that the drone can be placed in the palm of the hand.

- Zhejiang University The Fast Lab Micro UAV Project

The Fast Lab Gaofei team of the Unmanned System and Autonomous Computing Laboratory of Zhejiang University is committed to the autonomous research of light and small UAV clusters, autonomous navigation of UAVs in complex environments, fully autonomous UAV swarms, UAV dynamic target tracking, A lot of achievements have been made in UAV dynamic obstacle avoidance and large maneuvering robust flight control. The representative research results in 2021 and 2022 are mainly based on the following micro-UAVs, as shown in Fig 4.

Model 1

Model 2

Model 3

Model 4

Model 5

Fig. 4. Five types of UAV from the Fast Lab Team

The size of Model 1 UAV is 57cm×57cm, and the main research contents are UAV autonomous navigation, fully autonomous cluster and dynamic obstacle avoidance. The size of the Type 2 UAV is 40.0cm×40.0cm×9.2cm, and its mass is 794.2 g. The main research content is autonomous navigation of UAVs in complex environments, fully autonomous

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swarms, and robust flight control for large maneuvers. The size of Model 3 UAV is 28 cm × 25 cm × 25 cm, and its mass is 847.7 g. The main research content is the autonomous navigation of air-ground dual-mode complex environment. The size of Model 4 UAV is about 30 cm × 30 cm, and the mass is 1400 g. The main research content is dynamic target tracking and high-speed obstacle avoidance perception. The mass of Model 5 UAV is 300 g, and the main research contents are dense forest leap, formation flight in unknown environment, multi-machine tracking, high-density staggered flight and random obstacle avoidance.

Key Technology of Micro UAV

For micro-UAVs, its small size and high manoeuvrability are especially suitable for environmental awareness and intelligence search in restricted spaces. The size miniaturization of micro UAVs benefits from the miniaturization of airborne equipment such as onboard processors, controllers, sensors and communication modules. The miniaturization of airborne equipment and advanced manufacturing of integrated circuits, advanced packaging and heterogeneous are closely related to architecture integration technology. The smaller size and lower flight speed of micro-UAVs cause their cruising Reynolds number to be much lower than that of ordinary aircraft, and the viscous and unsteady effects at low Reynolds numbers will seriously affect the wing lift and flight stability of micro-UAVs, so the aerodynamic design at low Reynolds number is crucial for micro UAVs. Restricted spaces, such as indoor environments or dense forests, usually have dense obstacles, so micro UAVs are required to have the ability to autonomously navigate and avoid obstacles in complex environments. The following mainly introduces the miniaturization of the airborne equipment of the micro-UAV, the aerodynamic design of low Reynolds number, and the research status of autonomous navigation and obstacle avoidance in complex environments.

1. Miniaturization of airborne equipment

With the continuous progress of integrated circuit advanced manufacturing, advanced packaging and heterogeneous/heterogeneous integration technology, unmanned platform hardware sensors, processors, communicators, etc. are also moving towards chip, intelligence, miniaturization and high integration. develop. In terms of sensors, the 3DM-GQ7 differential navigation module from Parker Lord of the United States integrates low-noise and low-drift inertial MEMS sensors and dual multi-band GNSS receivers, with a size of only 76 mm×68.6 mm×13.3 mm and a mass of only 78 g. Tactical grade navigation accuracy. STMicroelectronics, Invensense, and Bosch have launched a variety of IMU inertial measurement units such as ASM330, IIM42652, and BMI088. The package size is only a few millimeters, which is very suitable for micro-UAVs. The Intelligent Systems Laboratory of the Federal Institute of Technology in Lausanne has developed a variable stiffness dielectric elastomer actuator, which weighs only 0.7 g and can withstand a certain stiffness change. It can be used on unmanned platforms to apply force or bear external weight. For unmanned platforms It is of great significance to increase the intelligent soft grip and improve the intelligence of the unmanned platform.

In terms of processors, microprocessors commonly used in unmanned platforms such as STM32F4, STM32F7 and ATSAME70Q21, etc., package size is only a few centimeters. NVIDIA Jeston Xavier NX and DJI Manifold 2 series high-performance computing processing microsystems have also been applied to micro unmanned platforms for unmanned platform flight control, target detection, target tracking, trajectory planning and map fusion, etc. NVIDIA Jeston Xavier NX measures only 103 mm × 90.5 mm × 34 mm, powers less than 20 W, can provide up to 21 TOPS of computing performance, and can efficiently run complex algorithms such as map construction and motion planning. The DJI Manifold 2 measures only 91 mm x 61 mm x 35 mm, has a maximum power consumption of 60 W, and can run multiple algorithms such as image processing, motion analysis, and neural networks.

In terms of communicators, wireless communication chips such as Qualcomm AR1021x, Imagination Technologies IMG IE1000 and Broadcom BCM43526KMLG are widely used in micro drones, and the package size is only a few centimeters. The Singapore Agency for Science, Technology and Research (A*STAR) launched a 5G millimeter wave application RF chip with a size of only 10 mm × 10 mm × 0.8 mm, an integrated 60 GHz wireless communication antenna, and a heat dissipation capacity of up to 5W. Peking University and the University of California, Santa Barbara jointly developed a silicon-based optoelectronic integrated system driven by an integrated microcavity optical comb, which can realize sub-GHz microwave photonic signal processing and T bit rate microcommunication, and propose micro-communication and microprocessing chip-level integration The multi-dimensional multiplexing architecture provides new development directions for 5/6G communication and optical computing, and provides support for unmanned cluster multi-node and high data bandwidth communication.

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2. Low Reynolds number aerodynamic design

In the field of low Reynolds number aerodynamic design, most of the research is based on rotor and flapping-wing micro-UAVs. The research directions mainly include aerodynamic characteristics simulation test and optimization, the influence of flapping-wing flexible deformation on aerodynamic characteristics, flapping-wing rotor combined design and noise reduction. design etc. The simulation test and optimization of aerodynamic characteristics mainly combine the characteristics of the flow field to analyze the relative camber and relative thickness of the rotor airfoil, the shape of the edge of the airfoil, the aspect ratio of the flapping wing, the camber and thickness of the airfoil, the folds of the airfoil, the flapping frequency of the flapping wing, and the flapping wing. The influence of the dynamic range and flapping mode on the aerodynamic characteristics such as lift and drag provides a reference for aerodynamic design and optimization. For example, Luo Shibin et al. based on the micro-rotor, combined with the k-kl-ω transition model, conducted research on the influence of Reynolds number, relative camber and relative thickness of the airfoil on the aerodynamic and flow field characteristics of the airfoil. The separation bubble and the relative camber of the airfoil can improve the aerodynamic performance of the airfoil such as lift and lift-to-drag ratio, and provide a reference for low Reynolds number airfoil design. Koning et al. proposed an unconventional airfoil with a sharp leading edge in the context of the Mars rotorcraft research, aiming at the problem of rapid performance degradation of the traditional airfoil due to the ultra-low Reynolds number, and the flow separation caused by the sharpening of the airfoil leading edge This makes the airfoil have better performance in low Reynolds number applications, and its peak lift-to-drag ratio can be increased by 17 % to 41 %. Wang Chao based on the unsteady and incompressible N-S equation, studied the micro-bionic flapping wing airfoil thickness, airfoil camber, airfoil fold structure, and wingtip flapping trajectory on the lift-drag coefficient of the flapping wing in the hovering and forward flight states , aerodynamic efficiency and flow field structure, the research results show that the flapping wing forward flight can use a thinner airfoil with positive camber to increase thrust and lift, and at the same time use the airfoil fold structure to improve the bending stiffness and deformation resistance ability, combined with the asymmetry of wing "swing-up" time and angle of attack to improve hover lift and aerodynamic efficiency.

3. Autonomous navigation and obstacle avoidance technology in complex environment

Autonomous navigation and obstacle avoidance in complex environments includes key technologies such as autonomous navigation, path planning, and dynamic obstacle avoidance. In recent years, such research results have been fruitful. Autonomous navigation and path planning methods emerge in endlessly. For example, Wang et al. proposed a multi-rotor trajectory planning method combined with unconstrained control cost minimization and smooth mapping, which transformed the general constrained multi-rotor planning problem into unconstrained optimization. This method can complete the trajectory planning of the 343.57 m long path within 0.29 s, and enable the UAV to fly safely in the underground parking lot at a speed of 12 m/s. In addition, the algorithm can realize the obstacle-avoiding flight of the multi-angle narrow windows continuously placed in the indoor environment of the micro-UAV. Zhou et al. proposed a planning method based on the distance field gradient without Euclidean symbols. The collision term of the penalty function of this method is calculated by comparing the collision trajectory with the collision-free guidance path. Only when the trajectory encounters a new obstacle, The obstacle information will be stored. The algorithm can complete actions such as entering and exiting the room and avoiding obstacles in an indoor cluttered environment. The narrowest passage in the test scene is less than 1 m, and the flying speed of the UAV can reach 3.56 m/s. In an outdoor scene with mixed trees and dense grass, the UAV can still reach a flight speed of more than 3 m/s even if the airflow affects the reliability of the map. Wu et al. proposed an elastic trajectory planning method that can be used in variable environments, which first uses nominal forces to generate motion primitives and uses them in the front-end dynamics path search, and then uses nonlinear model predictive control as a local planning, combined with Hamilton-Jacobi forward accessibility analysis to calculate the dynamic errors caused by external forces. The method is tested based on a micro-UAV. The running time of the algorithm is 10 ms. The UAV can also stably resist interference and conduct autonomous navigation in the cluttered forest with a wind speed of 3.1 m/s, and the flight speed can reach 2.5 m/s.

Future trends

1. Integrated and generalized airborne equipment

With the continuous development of integrated circuit advanced manufacturing, advanced packaging and heterogeneous/heterogeneous integration technology, micro-UAV airborne equipment has achieved remarkable results in miniaturization, but in the

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integration of airborne equipmen and general There is still a lot of room for improvement to the extent of. Future airborne equipment can adopt open interconnection interface standards, integrate core processors, integrated photoelectric sensors, and integrated radio frequencies, and reduce the quality, volume, and power consumption of redundant components through integrated design. At the same time, build a general-purpose task processing platform, a general-purpose radio frequency processing platform, and open sensors to achieve a high degree of reuse of software and hardware modules on different platforms, improve the intelligent, flexible and groupable capabilities of airborne equipment, and meet all-round operational needs.

2. Aerodynamic design cross-media and stealth

In the field of low Reynolds number aerodynamic design of micro-UAVs, there have been many research results on the optimization design of lift-drag aerodynamic characteristics, aeroacoustics optimization design, and the exploration and realization of bionic flight mechanism, and related research has gradually expanded from single-medium aircraft to cross-medium aircraft. In the future, we can further explore the mechanism of micro-bionic aircraft with high lift and long endurance. At the same time, we can develop aerodynamic calculation and test methods for general-purpose micro-aircraft across media, and design aircraft structures and shapes with good propulsion performance and stealth performance in different media. Covert, cross-media situational reconnaissance of aircraft.

3. Intelligent

Micro UAVs have made great progress in intelligence, which is mainly due to the progress of autonomous navigation and obstacle avoidance algorithms and intelligent control algorithms based on artificial intelligence, which enables micro UAVs to use various sensors for environmental perception. And realize independent planning and decision-making. However, the current degree of intelligence of micro-UAVs is not high enough, and the versatility and adaptability of various intelligent algorithms for different complex dynamic obstacle environments are not strong enough, and further optimization is needed. At the same time, the intelligent control methods of micro drones are not flexible enough. At present, most drones are controlled based on onboard control algorithms. In the future, biometric technologies such as iris recognition, gesture recognition and brain wave recognition can be combined to further enrich The control method of micro-UAV improves the level of intelligence.

Conclusions

Micro UAVs are especially suitable for situational reconnaissance and intelligence collection in indoor or urban environments, and there are a wide variety of micro UAVs that have been announced so far. With the rapid development of integrated circuit advanced manufacturing, advanced packaging and heterogeneous/heterogeneous integration technology, the miniaturization effect of micro UAV airborne equipment is remarkable, but the degree of integration and generalization of airborne equipment needs to be improved. In terms of low Reynolds number aerodynamic design, the optimization of aerodynamic characteristics such as lift and drag, the optimization of aeroacoustics, and the exploration and realization of bionic flight mechanisms have become the mainstream of research, and research on trans-medium general-purpose micro air vehicles is also underway. In terms of autonomous navigation and obstacle avoidance technology in complex environments for micro-UAVs, the mainstream methods are mostly based on vision and radar. At present, it has been able to perform relatively rapid autonomous navigation and dynamic obstacle avoidance in some indoor and outdoor environments with obstacles, and these Algorithms are gradually extended from single or single-mode UAVs to multi-mode or cluster UAVs, but the adaptability and versatility of the algorithm in complex, dense and dynamic obstacle environments still need to be optimized. As micro-UAVs become more and more intelligent, environmental versatility and adaptability become stronger, and cluster coordination and control strategies become more efficient and robust, micro-UAVs will definitely play an important role in future information warfare. a seat.

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Хаоян Лі

ОГЛЯД СТАНУ РОЗВИТКУ ТА МАЙБУТНІХ ТЕНДЕНЦІЙ МІКРОБПЛА

Стаття «Статус розвитку та майбутні тенденції розвитку мікро-БПЛА» представляє поглиблений аналіз еволюції та перспективних досягнень мікро-безпілотних літальних апаратів (мікро-БПЛА). Вступ простежує походження мікро-БПЛА до програми DARPA «Мікроповітряні транспортні засоби», зосереджуючись на їхніх компактних розмірах, легкій вазі та багатофункціональних можливостях для таких завдань, як розвідка на полі бою та ситуаційне спостереження.

У розділі про стан розробки описано прогрес від ранніх моделей, таких як «MSI», «Black widow», «Nano Hummingbird» і «Black hornet», до останніх ітерацій, таких як «Black hornet3», «MetaFly» і «RoboBee». X-Wing». Ці моделі демонструють значний прогрес у мікро-нанотехнологіях та системній інтеграції, покращуючи їх застосування в різноманітних середовищах.

У статті також висвітлюються типові дослідницькі проекти, підкреслюючи зростаючий акцент на штучному інтелекті та кластерах мікро-БПЛА. У ньому згадуються важливі ініціативи, такі як проект зграї БПЛА «Сіра куріпка», проект CICADA та швидкий легкий автономний проект (FLA), які зосереджені на дослідженні кластерів, навігації в приміщенні та на відкритому повітрі та уникненні перешкод.

Далі обговорюються ключові технологічні аспекти, включаючи мініатюризацію бортового обладнання, аеродинамічну конструкцію з низьким числом Рейнольдса, а також автономну навігацію та уникнення перешкод у складних умовах. У статті докладно розповідається про те, як малий розмір і висока маневреність мікро-БПЛА придатні для пошуку розвідувальної інформації в обмеженому просторі, і як їх конструкція адаптується до аеродинаміки з низьким числом Рейнольдса та складних навігаційних вимог.

Розділ майбутніх тенденцій передбачає подальший прогрес в інтеграції та узагальненні бортового обладнання, крос-медіа аеродинамічного дизайну та підвищення інтелекту мікро-БПЛА. Він передбачає розробку більш інтелектуальних методів керування, включаючи біометричні технології, для покращення функціональності мікро-БПЛА в складних динамічних середовищах.

На завершення в статті стверджується, що мікро-БПЛА стають все більш придатними для різноманітних застосувань, особливо для внутрішньої та міської розвідки. Проте в ньому вказується, що є можливості для вдосконалення інтеграції та узагальнення бортового обладнання та розробки більш універсальних та адаптивних автономних навігаційних технологій. У статті стверджується, що оскільки мікро-БПЛА стають більш розумними та адаптованими, вони відіграватимуть вирішальну роль у майбутніх інформаційних війнах.

Ключові слова: мікро БПЛА; мініатюризація бортового обладнання; аеродинамічна конструкція з низьким числом Рейнольдса; автономна навігація та уникнення перешкод

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REVIEW DEVELOPMENT STATUS AND FUTURE TRENDS OF MICRO UAVS

The article "Development Status and Future Trends of Micro UAVs" presents an in-depth examination of the evolution and prospective advancements in micro unmanned aerial vehicles (micro-UAVs). The introduction traces the origin of micro-UAVs to the DARPA's "Micro air vehicles" program, focusing on their compact size, lightweight, and multifunctional capabilities for tasks like battlefield intelligence and situational surveillance.

The development status section outlines the progression from early models like the "MSI," "Black widow," "Nano Hummingbird," and "Black hornet" to more recent iterations such as the "Black hornet3," "Meta Fly," and "Robo Bee X-Wing." These models demonstrate significant advances in micro-nano technology and system integration, enhancing their application in diverse environments.

The article also highlights typical research projects, underscoring the growing emphasis on artificial intelligence and micro-UAV clusters. It mentions significant initiatives like the "Grey Partridge" UAV swarm project, the CICADA project, and the Fast Lightweight Autonomous Project (FLA), which focus on cluster research, indoor and outdoor navigation, and obstacle avoidance.

Key technological aspects are discussed next, including the miniaturization of onboard equipment, low Reynolds number aerodynamic design, and autonomous navigation and obstacle avoidance in complex environments. The article elaborates on how the small size and high maneuverability of micro-UAVs are suitable for intelligence search in restricted spaces, and how their design is adapting to low Reynolds number aerodynamics and complex navigation requirements.

The future trends section predicts further advancements in the integration and generalization of onboard equipment, cross-media aerodynamic design, and increased intelligence of micro-UAVs. It anticipates the development of more intelligent control methods, including biometric technologies, to enhance the functionality of micro-UAVs in complex, dynamic environments.

In conclusion, the article asserts that micro-UAVs are increasingly suitable for varied applications, especially in indoor or urban reconnaissance. However, it points out that there is room for improvement in integrating and generalizing onboard equipment and developing more versatile and adaptive autonomous navigation technologies. The article posits that as micro-UAVs become more intelligent and adaptable, they will play a crucial role in future information warfare.

Keywords: micro UAV; airborne equipment miniaturization; low Reynolds number aerodynamic design; autonomous navigation and obstacle avoidance

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