Application, Development and Countermeasures of Intelligent Navigation Technology in the Field of UAV

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Abstract. Navigation technology development is one of the core key technologies to promote the intelligent development of UAVs, and is an important technical guarantee to support the complex mission attempt of UAVs and their formations. This paper introduces the main navigation means and application scenarios of UAV platforms, analyzes the development of UAV navigation technology applications at home and abroad, outlines the gaps in UAV navigation technology at home and abroad, and provides an outlook on future development trends.

Keywords: UAV · Navigation technology · Visual navigation · integrated navigation

1 Introduction to the Main Navigation Means of the UAV Platform

Currently, the navigation technologies used by UAVs mainly include inertial navigation, satellite navigation, and combined inertial/satellite navigation technologies, etc. Some UAVs also use visual navigation and astronomical navigation to achieve long-duration autonomous flight [1]. The details are described as follows.

(1) Inertial navigation is the only navigation means that can continuously output full parametric navigation parameters and is a necessary information source for UAV flight control, but its navigation errors accumulate and disperse with time [2]. Therefore, it must be augmented with other means of navigation.
(2) Satellite navigation with high accuracy, easy integration, and low cost is a common configuration for UAV navigation systems, but it has the risk of failure in jungle, urban occlusion, or electromagnetic interference environments [3].
(3) Astronomical navigation is characterized by strong anti-jamming ability and high accuracy of autonomous navigation, but it is costly and easily affected by weather environment [4]. Therefore, it is mainly applied in large military UAV platforms.
(4) As the "eyes" of UAVs, vision sensors have become standard for all types of UAVs, and visual navigation is to obtain carrier position and attitude information from the rich environmental information and carrier motion information provided by visual images. It can provide high-precision correction information for inertial guidance in

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the satellite navigation denial environment, and gradually becomes a hot spot and the main development direction in the field of UAV navigation research today [5].

In UAV navigation, it is important to choose the appropriate navigation technology according to the different tasks and scenarios of the UAV. To ensure reliable mission execution and safe flight, multiple navigation means are usually required [6]. The leading foreign UAV companies have researched and developed their own unique combined inertial/visual/satellite navigation solutions, demonstrating excellent navigation performance in different usage scenarios.

2 Analysis of the Application Scenarios of Navigation Technology in UAV Platforms

Combined with domestic and international UAV missions and applications, the main application scenarios of navigation technology can be summarized as follows.

2.1 UAV Autonomous Landing and Recovery Application Scenarios

UAVs performing autonomous landing, ship landing, and recovery tasks are one of the main occasions for UAV accidents, and the number of accidents occurring during recovery or landing of UAVs is statistically two to three times higher than the total number of accidents occurring in other processes. UAV precise positioning and attitude technology and UAV/landing platform precise relative navigation technology are the core key technologies for UAVs to perform autonomous and safe landing on moving targets or moving carriers [7].

2.2 UAV Path Planning and Autonomous Obstacle Avoidance Application Scenarios

UAVs require navigation systems to provide accurate position, attitude, heading and velocity information during path planning and stable flight control. In addition, in order to safely avoid fast-moving objects, UAVs also need navigation technology to integrate with environment perception technology to achieve an efficient, low-latency processing response of target perception-relative positioning-relative motion prediction-obstacle avoidance planning [8, 9]. Therefore, the accuracy performance, reliability, stability, and real-time of the navigation information directly affect the flight quality and flight safety of UAVs.

2.3 Specific Target Tracking Application Scenarios

Real-time tracking for specific targets is one of the main applications of search and reconnaissance UAVs [10], such as tracking of moving targets in military combat ground strikes, tracking of criminal vehicles in urban counter-terrorism, and tracking of people drifting with the waves in maritime search and rescue. The traditional UAV processing method is to acquire the target image and then transmit it down to the ground station for processing through a wireless link, and then generate a control signal to upload to the UAV, and the image transmission is easily interfered with and the transmission lag affects the control of the UAV and the stable tracking of the target. [11] Based on navigation technology, detection and recognition of moving targets in image sequences, establishment of a unified spatial reference and obtaining various motion parameters such as position, attitude and velocity of the target, which can adaptively adjust the UAV flight attitude to achieve specific target tracking, will further enhance the automation and intelligence of UAV flight control [12, 13]. For example, the map constructed by ALAM [14] is called High Definition Map (HD Map) [15], and the UAV is able to know its position and complete subsequent specific tasks.

2.4 Global Navigation Application Scenarios in Complex Environments

Autonomous navigation capability is an important part of UAV combat capability. UAVs have to complete a series of tasks such as takeoff, navigation and landing in various complex mission environments autonomously, and when faced with complex environments such as narrow spaces in city streets, inside buildings, dense forests and canyons, and strong electromagnetic interference, a systematic navigation solution that can adapt to the full range of mission scenarios is urgently needed. Visual navigation is very flexible, either based on image sequences or natural/manual markers for matching localization, or with inertial measurement units (IMUs) to build visual inertial odometers (VIOs), which can meet the requirements of different mission scenarios. For example, ORB-SLAM [16] forms a complete system for tracking [17], repositioning [18]and map construction [19].

2.5 UAV Cluster Relative Navigation Application Scenario

High-precision relative navigation information is an important guarantee for the implementation of flight missions such as close formation flight and cooperative operations of UAV clusters. In the existing unmanned cluster relative navigation systems, most of them are based on satellite information to achieve high-precision positioning, which is highly susceptible to enemy interference and less reliable in the battlefield environment, and are mostly inadequate [20, 21]. By combining visual navigation with inertial navigation, the relative line-of-sight vector of formation UAVs under the autonomous coordinate system of the carrier aircraft can be obtained to correct the relative position information between formations, which can effectively compensate for the degradation of relative positioning accuracy caused by the loss of satellite navigation signals.

3 Status of Foreign Applied Research

3.1 U.S. Army Unmanned Platform Navigation Technology Planning

In recent years, the application of foreign unmanned aircraft navigation systems and related research has continued to advance. in August 2018, the U.S. Army released a new version of the Integrated Roadmap for Unmanned Systems (2017–2042) [22],

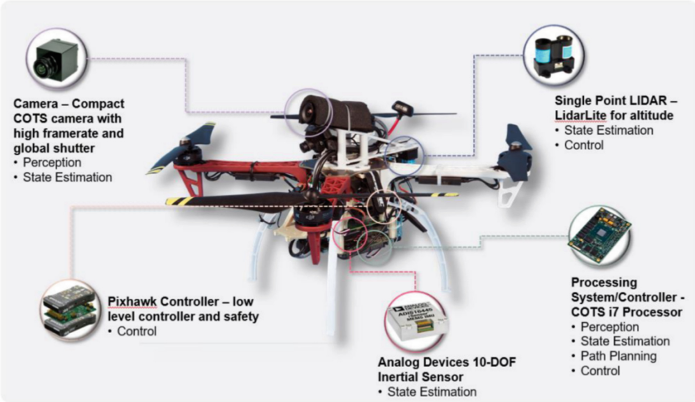

Fig. 1. FLA project system integration scheme [23]

which serves as the top-level guidance document for the development of unmanned systems in the U.S. Army specifying the need for unmanned systems to focus on improving perception and navigation capabilities. The U.S. Department of Defense Advanced Research Projects Agency (DARPA) has invested heavily in unmanned systems in areas such as environmental awareness and autonomous navigation technologies, supporting a large number of R&D programs to support the U.S. dominance in future unmanned aircraft technologies. For example, DARPA's Fast Lightweight Autonomy (FLA) program, launched in 2015, aims to develop new technologies that will allow small UAVs to navigate autonomously in obstacle-ridden environments such as buildings, with only a high-resolution camera, LIDAR or inertial measurement unit on board. The project aims to develop new technologies that enable small UAVs to navigate and fly autonomously and collect situational awareness data in obstructed environments, such as buildings, using only high-resolution cameras, LIDAR or inertial measurement units.

The FLA project is divided into two phases: the first phase, conducted in 2017, tested the algorithms and robustness of the UAV in real-world environments, verifying the aircraft's rapid adjustment from bright sunlight to dark building interiors, sensing and avoiding all types of obstacles, and traversing long distances in featureless environments; the second phase, conducted in 2018, saw the research team demonstrate the latest FLA technology in urban environments to perform real-world missions, demonstrating advanced algorithms that can transform small UAVs into equipment capable of autonomously performing military missions, such as previous reconnaissance missions in urban environments filled with enemy forces (Fig. 1).

3.2 Introduction of Foreign Typical Unmanned Platform Navigation Products

In addition, many foreign technology-leading UAV technology R&D companies have carried out research on airborne navigation system solutions based on visual navigation and launched representative combined navigation products, of which the more typical navigation system solutions are introduced as follows.

3.2.1 Alternative Navigation Systems from Honeywell

In 2022, Honeywell introduced its Alternative Navigation Systems and successfully demonstrated several advanced alternative navigation technologies to aid and enhance the availability, integrity and performance of inertial navigation solutions to seamlessly navigate even when GPS signals are blocked, interrupted or unavailable, with technology tests on the Embraer E170 aircraft and the AgustaWestland AW139 helicopter for technical testing (Fig. 2).

Alternative Navigation Systems uses sensors such as cameras, star trackers, radar and radio to augment or supplement inertial navigation systems that provide critical position, velocity and heading information in GNSS denial environments. Technologies successfully demonstrated on the E170 and AW139 include.

- Vision-assisted navigation: Honeywell's vision-assisted navigation system achieves GPS-like performance on the E170 and AW139 platforms in the face of GPS denial, using real-time vision-matched navigation to provide passive, non-interference and highly accurate absolute position.
- Astronomical Aided Navigation: Honeywell's astronomical aided navigation system on the E170 airborne platform achieves 25-m accuracy (CEP50) and the world's first airborne platform demonstration of a resident space object (RSOs)-based navigation solution that uses star trackers to observe stars and RSOs to provide a passive, non-interference solution in GPS GPS-like accuracy in denied or spoofed conditions.
- Magnetic Anomaly Assisted Navigation: Honeywell has conducted the world's first real-time magnetic anomaly assisted navigation on the E170 airborne platform, which is truly a historically important technology that implements passive, non-interference, all-weather and all-weather technology in the actual airborne environment compared to the previous geomagnetic navigation in special environments. to accurately identify the position of the aircraft.

Honeywell also demonstrated the Compact Inertial Navigation System, which, when used in combination with its advanced GPSDome (anti-jamming device), is capable of tracking GPS satellites in the presence of GPS interference in a more hostile jamming environment, resulting in reduced performance degradation from GNSS rejection and significantly improved navigation system position accuracy and integrity performance.

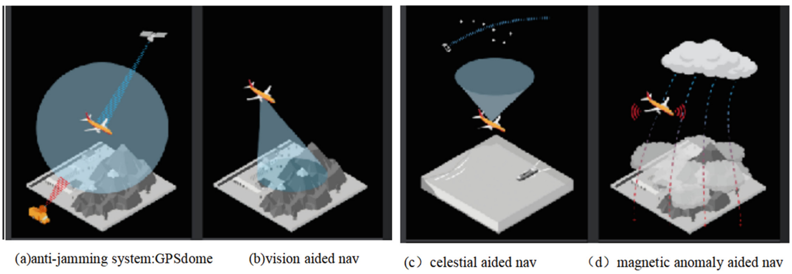

Fig. 2. Alternative Navigation Systems from Honeywell

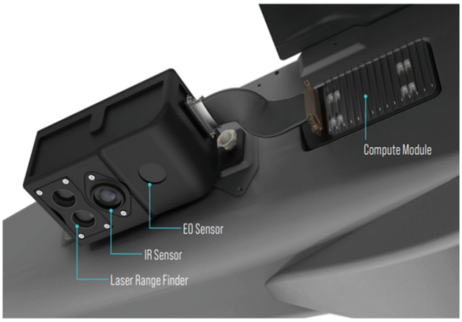

Fig. 3. Aero Vironment's Puma™ VNS[1]

3.2.2 Aero VIRONMEnt's Puma™ VNS

Aero Vironment, Inc. is a major U.S. unmanned aircraft systems (UAS) and tactical missile systems developer, developer, manufacturer, technical support and operator. The company's current major customers include the U.S. Army, Air Force, Special Operations Forces, and other government departments and commercial customers, among others. in 2022, Aero Vironment introduced the Puma VNS visual navigation system for the Puma 2 AE and Puma™ 3 AE small unmanned aircraft systems (SUAS), providing users with advanced navigation capabilities, features and functionality.

As shown in Fig. 3, the Puma VNS visual navigation system uses vision sensors to collect image data and track ground features, based on an embedded computing module used to process and determine the precise position of the aircraft in flight. Designed with the operator in mind, the system automatically transitions to GPS denial navigation mode without any operator input to adapt to the complex and changing battlefield environment. The system is modular in design, weighing only 0.54 kg, and can be integrated into the company's Puma family of UAVs as a standalone retrofit kit.

3.2.3 Asio Technologies NavGuard Series Optical Navigation System

Asio Technologies is an Israeli company specializing in the development of navigation, positioning, mission planning, mission management and systems integration systems, providing advanced technology solutions for military and paramilitary applications. The company has developed the NavGuard family of compact, autonomous optical navigation systems that use advanced machine vision, artificial intelligence, optics and sensor fusion technologies that can be installed on a variety of UAV platforms to enable seamless, accurate, all-weather autonomous navigation in areas where GNSS signals are spoofed and unusable.

The main features of the NavGuard series of optical navigation systems are as follows:

- NavGuard is optimized for all types of tactical UAV platforms, with leading positions in key parameters such as size, weight and power.

[1] www.avinc.com

Technical Specs
Lightweight：0.185kg
Low Power Consumption：4~6W
Thermal Imaging
High Accuracy,Drift-Free Positioning
Advance Machine Vision Capabilities

Fig. 4. Asio Technologies' NavGuard NOCTA Mini product[2]

- NavGuard processes optical video stream geographic information in real time and based on an on-board geodatabase to achieve precise positioning with low latency.
- NavGuard is a completely self-contained system module that integrates the computing module, map database and camera into a small, lightweight and low-power system with an architecture that ensures it works independently without external interference (Fig. 4).

3.2.4 UAV Navigation VNS

UAV Navigation specializes in the design of guidance, navigation and control system solutions for UAVs. As shown in Fig. 5, the company is based in Spain and its flight control and navigation solutions are successfully applied to a wide range of UAVs including high performance tactical UAVs, vertical take-off and landing fixed wing UAVs, aerial targets, micro UAVs and helicopters.

In 2022, UAV Navigation unveiled its latest visual navigation system, VNS, which combines "visual odometry" and "pattern recognition" technology with other sensors on the aircraft to ensure superior accuracy performance to provide absolute position, direction and relative motion information to the aircraft. The system's very small size and weight allows it to be installed in Class I and Class II unmanned systems, providing accurate navigation information in flight without compromising aircraft autonomy or payload capability when GNSS signals are lost

3.3 Foreign Unmanned Platform Navigation Technology Development Trend Analysis

- In terms of system composition: visual navigation, geomagnetic navigation, astronomical navigation and other autonomous navigation means to assist inertial navigation, to improve the survivability of the UAV platform in complex environments and mission attempt capabilities.
- In the development of hardware: standardized and modular design requirements, chip-based integration means to achieve a highly integrated design of a variety of navigation sensors, computers, and databases to form a low-cost, miniaturized, low-power system.

[2] Navigationguard.com.

Technical Specs:

TYPICAL DEAD-RECKONING DRIFT FIGURES	
Standard AHRS-INS(3rd party)	100m/min
UAV Navigation POLAR AD-	<35m
Visual Navigation System	<0m/min(previously flown area)<10m/min (unknown
TECHNICAL SPECIFICATION	
Compatibility	All types of UAS
Weight	90g
Size(mm,H×W×L)	22×46×77
Enclosure Material	Grade 6082 Aluminium Alloy
IP Rating	Designed to conform with IP66
Voltage Supply	9 to 36 V DC
Power Consumption	5w @ 12VDC

Fig. 5. UAV Navigation's VNS products.[3]

- In the development of algorithms: the use of machine learning and other advanced intelligent algorithms to achieve multi-source navigation information fusion, enhance the robustness of navigation information, accuracy stability, with the rapid realization of navigation system reconstruction and information stability output in the case of partial failure of navigation means.
- In the application of navigation services: based on collaborative open architecture to develop swarm collaborative navigation, on the basis of meeting the needs of unmanned platform stand-alone navigation services, the integration of communication technology, relative positioning technology, to achieve enhanced navigation and positioning capabilities of unmanned platform clusters, to improve the denial of environmental collaborative combat capabilities.

4 Status of Domestic Application Research

4.1 Description of Domestic Developments

With the explosive growth of domestic UAV application demand, China has made considerable achievements in UAV vision-aided navigation, and many research institutions have developed different types of verification prototypes and conducted verification tests of specific algorithms for inertial/visual/GNSS combined navigation. At present, domestic companies and industrial sectors have launched airborne inertial/visual/GNSS

[3] http://www.uavnavigation.com

combined navigation products for specific scenarios, but in general, most domestic products belong to customized applications, with a single functional mode and not enough variety, and modular products based on functional integration have not yet been used on a large scale. Among them, the civil representative DJI Guidance vision sensing navigation system is one of the representatives.

DJI's Guidance is a sensor system that provides reference information for intelligent navigation. It uses a combination of ultrasonic sensors and cameras to sense the three-dimensional environment in real time, providing speed, position and obstacle distance observation information to the carrier. At the same time, the system can be used for industry users and secondary development users, and can be developed to extend other vision applications.

Guidance vision sensing navigation system forms an auxiliary positioning system by installing each module onto the UAV and using it in conjunction with an intelligent system. Its main workflow is as follows:

- the vision sensing module collects images through the camera and ultrasonic data through the ultrasonic sensor;
- the vision processing module receives images and ultrasonic data and performs calculation processing;
- the positioning information is transmitted to the UAV flight control system through the CAN-Bus connection line or to other intelligent systems through the USB/UART connection line, thus realizing auxiliary speed measurement, positioning and obstacle sensing functions (Fig. 6).

The main performance indicators of Guidance visual sensing navigation system are as follows:

- Velocimetric range: 0 ~ 16 m/s (2 m above ground).
- Speed measurement accuracy: 0.04 m/s (2 m above the ground).
- Positioning accuracy: 0.05 m (2 m above the ground).
- Effective observation range: 0.20 m ~ 20 m.
- Environmental requirements: good lighting conditions; obvious texture of the observed objects.

Fig. 6. DJI Guidance vision sensing navigation system[4]

[4] Https://developer.dji.com/cn/

4.2 Technology Gap Analysis

Compared with foreign countries, there are significant gaps in intelligent navigation technology and its applications based on the vision technology system in China, specifically:

- domestic intelligent navigation technology is still in the primary stage, the product maturity is low, the application scene is not wide. In addition to the DJI company developed civilian products, has not yet formed a combination of military and civilian, commercial and cutting-edge development ideas. In response to this situation, on the one hand, we need to accelerate the development of high-performance, low-cost navigation sensor technology and seize the source of navigation technology development; on the other hand, we need to develop advanced intelligent fusion algorithms on the basis of the existing domestic navigation sensor technology capabilities to realize the fusion enhancement of multiple navigation means.
- Domestic vision-based miniaturized UAV intelligent navigation can only achieve relative navigation, but not yet absolute position navigation. To address this shortcoming, on the one hand, it is necessary to carry out research on high-performance vision processors to improve the video stream processing capability; on the other hand, it is necessary to make comprehensive planning for the development of various technologies such as satellite remote sensing map transmission, matching navigation and intelligent image recognition from the top level to lay the technical foundation for the formation of visual absolute navigation and positioning capability.
- Domestic small UAV autonomous aided navigation means in addition to relative visual navigation, lack of astronomical navigation, geomagnetic navigation and other information, it is difficult to form a reliable high-precision autonomous navigation capability. To address this gap, it is necessary to prioritize the development of intelligent navigation systems based on the fusion of visual, astronomical and geomagnetic information in medium/large UAV platforms to make up for the shortcomings of visual sensors, astronomical sensors, geomagnetic sensors and data processing units that are difficult to miniaturize and lighten in the short term, and then prioritize to ensure the feasibility and maturity of the technical path of the above-mentioned autonomous navigation means, and provide theoretical support for the subsequent lightweight and miniaturization of key sensors Theoretical support for system application requirements.

5 Conclusion

In the face of the increasingly tense and complex international situation, UAV combat, which has the advantages of low cost, high speed and intelligence, deployment mobility, good stealth, and no casualties, will receive more widespread attention. Among them, the navigation technology is one of the core key technologies for safe navigation/landing of UAVs and mission accomplishment. At present, domestic and foreign civilian UAVs mainly use low-cost inertial navigation technology as the core of the navigation system, with satellite navigation as a conventional auxiliary navigation means. However, for special application scenarios and platforms, autonomous navigation capability and navigation system reliability have become the focus of attention. At present, astronomical navigation, geomagnetic navigation and visual navigation are mainly used as auxiliary navigation means at home and abroad, and intelligent information source selection algorithms and optimal estimation theory are used as the basis to realize multi-source navigation information fusion enhancement and improve the autonomous navigation capability and navigation system reliability of UAV platforms. Hot spot.

At present, there is still a large gap between domestic unmanned platform navigation technology and foreign advanced technology, mainly because the front-end sensor technology is relatively underdeveloped; the development of map database supporting visual matching absolute positioning is not yet perfect; the back-end multi-source navigation information fusion technology application verification is not yet sufficient. Therefore, China needs to accelerate the research of UAV navigation technology and develop inertial/visual/satellite/geomagnetic combination navigation products with integrated sensor chip and highly intelligent algorithms to meet the demand for navigation security services for UAV platforms in many fields such as military, rescue and industry.

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