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Framework and requirements for civilian unmanned aerial vehicle flight control using artificial intelligence

Recommendation ITU-T F.749.13

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Recommendation ITU-T F.749.13

Framework and requirements for civilian unmanned aerial vehicle flight control using artificial intelligence

Summary

Recommendation ITU-T F.749.13 provides a framework of civilian unmanned aerial vehicle flight control using artificial intelligence, including the flight navigation control of a civilian unmanned aerial vehicle (CUAV) itself and the specific flight control based on the vertical industry application requirements. Although CUAVs have been widely used in industry and consumption areas, there are also problems in the development of CUAVs. In addition to the policy and legal supervision, the other problem is how CUAVs avoid obstacles during the flight, and how the CUAVs applied in the vertical industry can automatically navigate, track or fly along a specific area according to the mission requirements, to achieve partial or complete autonomous flight and control.

This Recommendation also provides a flight control framework and functional requirements for each specific implementation. This way the product and system integrators can design and produce specific products and systems according to this framework.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T F.749.13	2021-06-13	16	11.1002/1000/14684

Keywords

Artificial intelligence, civilian unmanned aerial vehicle, flight control.

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FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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Framework and requirements for civilian unmanned aerial vehicle flight control using artificial intelligence

1 Scope

This Recommendation provides a framework of civilian unmanned aerial vehicle flight control using artificial intelligence (AI), including the flight navigation control of a civilian unmanned aerial vehicle (CUAV) and the specific flight control according to the vertical industry application requirements. The regulations and supervision of civilian unmanned aerial vehicle flights are out of the scope of this Recommendation.

The scope of this Recommendation includes:

– Framework of CUAV flight control using AI,

– Functional requirements for CUAV flight control using AI.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

None.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 civilian unmanned aerial vehicle [b-ITU-T F.749.10]: An unmanned flying device controlled by a ground control station or telecontroller via various wireless communication means. It usually consists of an aeroplane body, a power device, aviation electrical and electronic equipment and mission payload equipment, etc. and is used in non-military application areas such as industrial and consumer areas to complete the specific operation and transportation of data including audio, video and image.

3.1.2 flight control system [b-ITU-T F.749.10]: This is the sum of all components and driving devices of instruction transferring, rudder motion. It is mainly composed of airborne and ground control terminals. The one that is airborne includes three parts: airborne sensors, steering engine and flight control units.

3.1.3 ground control station [b-ITU-T F.749.10]: A ground control station is a device which is used to realize the functions of mission planning, flight control, payload control, flight path display, parameter display, image and video display and mission information displaying, recording, and distributing.

3.1.4 mission payload equipment [b-ITU-T F.749.10]: The mission payload equipment consists of an audio/video/image acquisition device, signal relay device, remote electronic detection/sense device, and other auxiliary devices.

3.1.5 telecontroller [b-ITU-T F.749.10]: A piece of equipment used by human beings to control an unmanned aerial vehicle. It is usually composed of an operating device, coding device, transmitting device, receiving device, decoding device, and executing mechanism.

3.1.6 artificial intelligence (AI) [b-ISO/IEC 2382]: An interdisciplinary field, usually regarded as a branch of computer science, dealing with models and systems for the performance of functions generally associated with human intelligence, such as reasoning and learning.

3.1.7 capability [b-ITU-R M.1224-1]: The ability of an item to meet a service demand of given quantitative characteristics under given internal conditions.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 flight control: It is the whole flight process to realize CUAV gesture stability and control, navigation and path planning, avoiding obstacles and emergency control, etc., including taking off, flying in the air, executing the mission and returning to the field.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

4G The 4th Generation Mobile Communication Technology

5G The 5th Generation Mobile Communication Technology

AI Artificial Intelligence

CPU Central Processing Unit

CUAV Civilian Unmanned Aerial Vehicle

GCS Ground Control Station

GNSS Global Navigation Satellite System

GPU Graphics Processing Unit

HDD High Definition Display

NPU Neural-network Processing Units

5 Conventions

In this Recommendation:

– The keywords "is required to" indicate a requirement that must be strictly followed and from which no deviation is permitted if conformance to this document is to be claimed.

– The keywords "is recommended" indicate a requirement that is recommended but which is not absolutely required. Thus, this requirement need not be present to claim conformance.

6 Introduction

Currently, with the rapid development of civilian unmanned aerial vehicles (CUAV), these unmanned aerial vehicles are widely used in industry and consumption areas such as agriculture and plant protection, power line and petroleum pipeline inspection, police & traffic security surveillance, disaster monitoring, express delivery, forestry and forest fire monitoring, etc. Although the manual control of CUAV can be realized by telecontroller and ground control station (GCS) in these applications; due to the complexity and uncontrollability of the external environment, or the specific mission requirements, it is still hoped that CUAVs have partial or whole automatic ability of take-off, flight control and landing. Thus, CUAVs need some degree of intelligence, to avoid obstacles, prevent collisions, and complete industrial application flight missions. For example, using CUAV to inspect the power line or oil pipeline requires CUAVs to fly along a specific route (capable of automatically navigating and avoiding obstacles) and to automatically adjust the flight height (capable of precise control of the flight state) and speed according to the shape of power line/oil line so that the high definition display (HDD) cameras in CUAV can easily check and diagnose power lines/pipelines.

At present, artificial intelligence (AI) technology has developed rapidly and has achieved great success in many fields, such as computer vision systems, pattern recognition, image recognition and so on. With the deep application of cloud computing and edge computing, all these provide a strong support platform for the training and modelling of AI.

This Recommendation provides a framework and functional requirements for each specific implementation, so the product and system integrators can design and produce specific products and systems according to this framework.

7 Framework of CUAV flight control using AI

The flight control system of CUAV is a resource-limited system. Therefore, the provision of algorithm and model of flight control need the help of the external system and platform.

Flight control using AI includes three aspects of data collection, processing and modelling, and application/execution process. Figure 1 presents a framework diagram of CUAV flight control using AI.

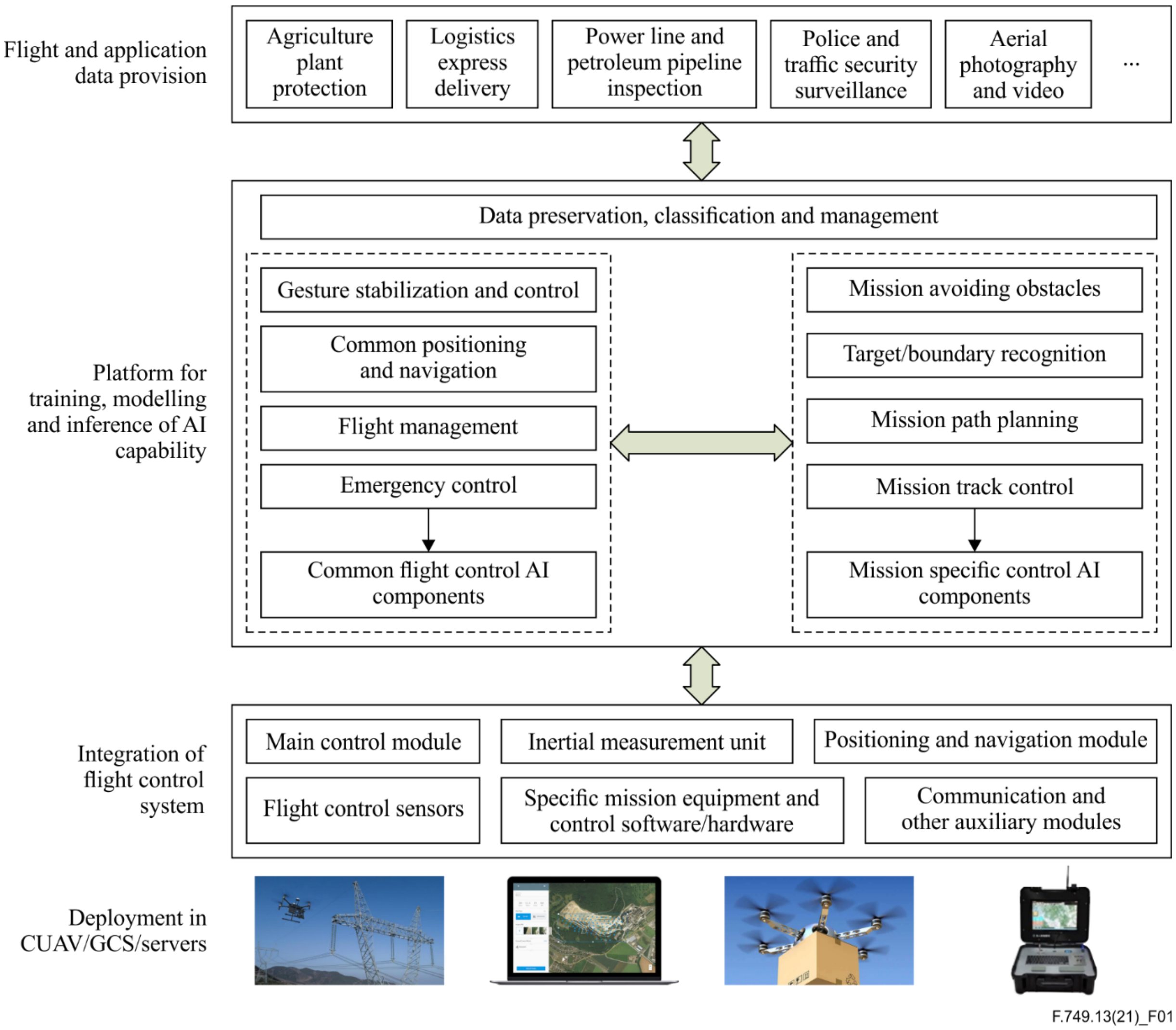

Figure 1 – Overview of framework diagram of flight control using AI

7.1 Flight and application data provision

AI algorithms, reasoning and modelling require a lot of flight data and vertical industry application flight control data collected by CUAV flight sensors and applications. The sensors include gyroscopes, accelerometers, barometers, global navigation satellite system (GNSS) modules, infrared sensors, laser sensors, ultrasonic sensors, visual sensors, and audio and video equipment carried by the mission payload. Application data from agriculture and plant protection, power line and petroleum pipeline inspection, police and traffic security surveillance, disaster monitoring, express delivery, forestry and forest fire monitoring, etc. will greatly promote the training and modelling of AI in a flight control system.

7.2 Platform for training model and inference of AI capability

The platform shall collect all kinds of flight control and application data, and the data will be classified, stored and managed. It is necessary to authorize access to this data before using them to provide data security and privacy and rights protection. The application of artificial intelligence in flight control systems requires the help of AI training frameworks (e.g., TensorFlow, etc.) and inference frameworks. They are usually deployed in a platform with central processing unit (CPU), graphics processing unit (GPU) and neural-network processing units (NPU) with required hardware resources for scheduling and using, for the implementation of massive training. The framework can also be a lightweight software framework running on a CUAV side, which can improve the operational efficiency and improve real-time and accuracy of flight control. To respond quickly and timely to the flight environment, complete automatic navigation and obstacle avoidance, the dedicated flight control chips and hardware can be deployed on a CUAV to provide basic computational capabilities for automatic navigation inference for vertical industry application scenarios.

Third-party software/middleware service providers, using an open AI platform, provide modular encapsulation of application-specific flight control algorithms based on large numbers of flight and application data provisions, or provide algorithm tools or middleware for flight control system integrators and application developers.

Common flight control AI capability components include but are not limited to the following:

– Gesture stabilization and control
– Common positioning and navigation
– Flight management
– Emergency control

Mission specific flight control AI capability components include but are not limited to the following:

– Mission avoiding obstacles
– Target/boundary recognition
– Mission path planning
– Mission track control

Common flight control capabilities, such as positioning and navigation, and flight management functions will relate to obstacle avoidance and path planning. Flight control for specific missions requires flight gesture stability and navigation. Hence, the classification of common flight control AI capability and mission specific flight control AI capability is not absolute. They interact and cooperate with each other to complete the entire flight process.

7.3 Integration of flight control system

CUAV manufacturers or flight control system integrators apply the above-mentioned common flight control and mission specific flight control AI capability components, including AI software and algorithms, hardware and chips, to the main control module, inertial measurement unit, positioning and navigation module, flight control sensors, specific mission equipment and control software and hardware, etc. to realize the partial or full-automatic flight control of CUAV.

8 Functional requirements for CUAV flight control using AI

The flight control in this Recommendation consists of two aspects, one is the common flight navigation control of a CUAV (including gesture stabilization and control, positioning and navigation, normal take-off and landing, etc.); the other is the specific mission flight control (including mission avoiding obstacles, tracking, or along a direction or specific area, etc.) based on the vertical industry application requirements.

8.1 Requirements for flight and application data provision

The data required by an AI algorithm, reasoning and modelling include but are not limited to the following:

– **Flight data**. Examples include maximum flat speed, cruise speed, minimum speed, height ceiling, the maximum usage height and minimum flight altitude, flight radius (referring to the distance from taking off to the far most point), pitch and tilt angle, the tilt angle degree, and the yaw angle degree, etc.

– **Vertical industry application flight data**. Examples include continuation time and maximum continuation time of flight, minimum turning radius, the maximum climbing rate and the maximum descent rate, maximum take-off weight, maximum mission payload equipment weight, positioning and the target location, mission path planning, and track control data, etc.
– **Power system and flight environment data**. Examples include motor speed, temperature, humidity, external wind speed, ambient temperature, power supply, image and video of the working area and environment obtained by mission payload equipment, recognition of specific target and environment, avoidance operation process, alarm operation data, etc.

8.2 Requirements for platform for training, modelling and inference of AI capabilities

Flight control using AI includes common flight control and mission specific flight control. The platform needs to complete the functions of training, modelling and inference of AI capabilities.

8.2.1 Requirements for common flight control AI components

Common flight control includes gesture stabilization and control, positioning and navigation, flight management, and emergency control. The AI training framework and platform use all kinds of flight data, combined with geographical fence and flight-prohibition zones data provided by the flight management department, to fulfil the training, modelling, and inference process for common flight control. The final products are the flight control AI software/algorithm, hardware/chips, which can be used by CUAV manufacturers or third-party flight control system integrators. The functional requirements for these AI components, such as software/algorithm, along with hardware/chips integrated with AI software and algorithm, include but are not limited to the following items:

8.2.1.1 Gesture stabilization and control

GS-01: CUAV is required to use an inertial measurement unit (flight attitude sensing equipment), air pressure sensor, ultrasonic sensor, etc. to realize CUAV gesture stability and control without GNSS positioning.

GS-02: CUAV is recommended to have online situational awareness and variable autonomy control capabilities to help achieve semi-automatic/automatic flight functions.

GS-03: When the autonomous flight of CUAV cannot be controlled by itself or needs to be taken over, it is required to switch to the telecontroller or GCS to take over, to restore the correct posture and state.

8.2.1.2 Common positioning and navigation

PN-01: CUAV is required to create two dimensions or three-dimension maps of the environment online or offline according to the environmental information obtained by various airborne sensors.

PN-02: CUAV navigation system is recommended to realize autonomous flight of designated route according to environment map, position, speed, and flight attitude of reference coordinate system.

PN-03: CUAV navigation system is recommended to realize navigation through GNSS, inertial guidance, or binocular vision, or use the combination of inertial guidance plus binocular vision plus GNSS.

PN-04: For a vertical industry application or indoor application, the GNSS is either not available or unable to meet the requirements. For this purpose, multiple small base stations (signal sources) are required to be used. The distances from the three base stations closest to the CUAV selected, along with the identifier and the receiving signal strength of the CUAV and the identifiers of small base stations (including their coordinates) are used to determine the CUAV coordinates.

8.2.1.3 Flight management

FM-01: Flight management function is required to complete CUAV flight process monitoring and flight control session management.

FM-02: Flight management function is required to record the mission path and its track.

FM-03: Flight management function is required to support the receiving track information transmitted by CUAV in real-time. The longitude, latitude and altitude data extracted and the corresponding position are then displayed in the map window, so that the operator can see the CUAV position information directly.

FM-04: Flight management function is required to support data playback mode. After receiving the flight data and saving the data, the whole process of the flight path can be reproduced through the data playback mode, including the position, attitude, and other important data of the CUAV, which is convenient for the analysis of the flight status and mission execution status of the CUAV.

8.2.1.4 Emergency control

EC-01: The flight control function is required to automatically record the flight path and calculate the return route when the control signal is disturbed, or the wireless control link is interrupted and realize the automatic return and landing.

EC-02: The flight control function is required to support the lock course to control the direction of CUAV when the direction cannot be identified.

EC-03: The flight control function is required to support the avoidance of the flight-prohibition zone and emergency management flight areas designated by the aviation management department.

8.2.2 Requirements for mission specific control AI components

The flight control process of a specific task is based on the common flight control. Therefore, the functional requirements of the two complement each other. The flight control process of the task load needs to be based on positioning and navigation to complete the mission path planning and track control, and at the same time, it is also required to realize the mission avoiding obstacles and target/boundary recognition. So, the functional requirements for these AI components, such as software/algorithm, along with hardware/chips integrated with AI software and algorithm, include but are not limited to the following items:

8.2.2.1 Mission avoiding obstacles

AO-01: CUAV is required to use one or several of infrared sensors, ultrasonic sensors, laser sensors, and visual sensors to sense environmental information and measure the distance of obstacles to avoid obstacles.

AO-02: CUAV is recommended to use the map model of flight area (e.g., two and three-dimensional map) to reasonably plan the route to bypass obstacles, so as to realize autonomous flight.

8.2.2.2 Target/boundary recognition

The identifications can be done on CUAVs or sent back to ground control stations (GCS) and cloud servers.

TR-01: For consumption applications, such as aerial photography, CUAV is required to distinguish the target object (such as people) from the environment, and constantly track and identify the moving target.

TR-02: For plant protection applications, CUAV is required to identify the crops and boundary of the field, e.g., trees, haystacks, electric poles and wires, as well as distinguish the boundary and narrow path between crops and farmlands.

TR-03: For applications related to the inspection of power lines and oil pipelines, CUAV is required to identify oil pipeline/power lines to monitor and cruise along the power line or oil pipeline and find whether there are any hazards or faults.

TR-04: For natural disaster monitoring related applications, CUAV is recommended to distinguish avalanche survivors, forest fires, disasters such as drought, flood, landslide as well as aquatic plants from floating garbage, and harmful liquids, etc.

8.2.2.3 Mission path planning

PP-01: CUAV is required to plan flight routes to fly a larger range and accomplish more tasks in a shorter time and cost.

PP-02: For vertical industry applications, CUAV is required to fly along specific directions and paths. For example, using CUAV to inspect the power line or oil pipeline requires CUAVs to fly along a specific route (capable of automatically navigating and avoiding obstacles) and to automatically adjust the flight height (capable of precise control of the flight state) and speed according to the shape of power line/oil line so that the HDD cameras in CUAV can easily check and diagnose power lines/pipelines.

PP-03: When multiple CUAVs are flying in a certain formation, the flight control system is required to ensure that the CUAVs in the formation avoid collision and can change the formation according to the defined mission requirements.

8.2.2.4 Mission track control

TC-01: CUAV is recommended to support the use of vector maps to control the track and realize a three-dimensional display with the current track control angle. The estimated total range of the CUAV can be displayed in the information prompt window, to make the track control and operation more intuitive.

TC-02: Mission track control function is required to support the mouse movements on the digital map. The latitude and longitude information of the point can be displayed at the mouse position, and new navigation points can be added by clicking the mouse to improve the efficiency of route planning.

8.3 Requirements for integration of flight control system

Flight control system includes the main control module, inertial measurement unit, positioning and navigation module, flight control sensors, specific mission equipment, control software and hardware, communication, and other auxiliary modules. These modules shall use some or all AI functions to meet the application requirements of different vertical industries in flight gesture control, positioning and navigation, obstacle avoidance, target boundary recognition, mission path planning and track control. The AI functions, algorithms, software/hardware should be implemented in the way of components, from which one or more components can be selected and utilized when integrating into vertical industry application systems. These will improve the integration efficiency of the system and shorten the development time.

FC-01: The integrated flight control system is required to be deployed to CUAV and GCS, or on the cloud servers. When deployed to the cloud server, it can make full use of the low delay, high bandwidth, and reliability of the 4th generation mobile communication technology / the 5th generation mobile communication technology (4G/5G) network and beyond to realize the data and commands of CUAV download and upload.

FC-02: The real-time data and images/videos acquired by CUAV sensors are recommended to be transported to the cloud servers through the 4G/5G network and beyond. The cloud shall use these data to complete the training, modelling, and inferencing of AI components. Sometimes, these data can be processed in real-time by the network edge computing system, and the processing results will be sent to the CUAV to control the flight of CUAV.

FC-03: For a vertical industry application or indoor application, the global navigation satellite system (GNSS) is either not available or unable to meet the requirements. Flight control system is required to interact with small base stations and select a small base station that is closest to the CUAV (the distance reaches a specified value). Then the small base station sends flight control instructions to the CUAV to complete the mission tasks.

Appendix I

Use case of civilian unmanned aerial vehicle flight control using artificial intelligence

(This appendix does not form an integral part of this Recommendation.)

In the process of low altitude plant protection, CUAVs may encounter obstacles such as cables, trees, buildings, etc. Thus, CUAVs must have the function of autonomous obstacle avoidance equipment to identify trees, haystacks, electric poles and wires. So, it is necessary to have an obstacle avoidance equipment such as laser radar, millimetre wave radar, binocular stereo vision, etc. Before spraying pesticides, CUAVs also need to identify crops and field narrow roads in the field. Figure I.1 presents some examples about the specific shape of the task area, path planning, and so on.

Figure I.1 – Examples of sloping fields, binocular vision and path planning

At present, many plant protection CUAVs have one or more environmental sensing equipment, such as infrared sensors, ultrasonic sensors, laser sensors, and binocular vision sensors which can measure the distance of obstacles and identify the environment. Many plant protection CUAV manufacturers or other flight control system integrators can use the existing flight control historical data, combined with the data of various sensors collected by CUAV on the fields to practise online (based on cloud computing technology or edge computing, etc.) or offline training, modelling and reasoning of the flight control system. The trained software and hardware can be used to form real-time flight action instructions with partial intelligence of achieving obstacle avoidance and completing mission flight process, as well as to shorten the time for route planning, flying a larger range and completing more tasks with less cost, and realize track control based on high-precision map. For example, through the collection of three-dimensional space XYZ coordinates, six degrees of freedom (6DOF), yaw angle (yaw), roll angle (roll), pitch angle (pitch), Euler angle, and other data, it can provide a coherent and fluent action data basis for CUAV's gesture control and motion planning. When the flight target area is modelled as an accurate three-dimensional map, the CUAV can go skimming flight based on the ultra-low altitude automatic terrain matching and realize automatic obstacle recognition and avoidance, position and gesture control.

Flight control system using AI can fly along a specific route (capable of automatically navigating and avoiding obstacles) and to automatically adjust the flight height (capable of precise control of the flight state) and speed, according to the shape of terraced fields or other shapes. The CUAV can sprinkle pesticide along a specific shape and at an appropriate height above the specific area, thus avoiding wastage of the pesticide.

In addition, many CUAV flight control systems have the following functions:

– Friendly user interface. Flight path and track of CUAV can be displayed graphically.

– In the route planning mode, with the mouse moving on the digital map of the target area, the longitude and latitude data of the point on the map can be displayed at the same time. At this time, click the mouse to automatically add points as a new waypoint in the route.

– After the actual flight process of a CUAV, the data is obtained and saved, the whole flight process of the CUAV can be reproduced through data playback mode.

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