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Use of rescue mode for UAV on the basis of STM32 microcontrollers

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ABSTRACT

The practical possibility of a guaranteed return of budget unmanned aerial vehicles (UAV) to area of the starting point in event of loss radio communication with a video camera or control panel is considered. In this regard, an experimental model of a flying wing with wingspan of 1000 mm and a flight weight of up to 500 g was built, on which a flight controller SPRacingF3 based on the STM32F303 microcontroller with a GPS receiver and a directional video camera was installed to provide FTP flights. Based on INAV firmware, main attention was paid to setting flight modes NAV RTH, NAV FAILSAFE to ensure a guaranteed return. The practical possibility of using GPS Rescue mode for Betaflight firmware to return quadrocopter to a point close in take-off coordinates was also considered. In this regard, an experimental prototype was built with a 250mm frame, but with which OMNIBUSF4V3 flight controller was installed based on STM32F405 microcontroller with a GPS receiver and a heading video camera for FTP flights. During flight tests, it was shown that GPS Rescue mode allows you to return UAV to the launch zone, subject to the settings presented in the work on the assembled quadcopter. When performing GPS Rescue mode, an important condition is the stable connection of GPS receiver with the number of satellites not less than those installed when setting up the firmware. It is established that for the return of UAV of the considered types it is not necessary to use a barometer and magnetometer, functions of which can be performed by GPS receiver.

Key words: OMNIBUSF4V3, OSD, Betaflight, INAV, GPS receiver, FPV, STM32F405, GPS Rescue, GLONASS, NEO-6M-0-001, SPRacingF3, microOSD.

1. INTRODUCTION

Technologically leading countries use unmanned aerial vehicles (UAV), both of rotor type (quadrocopters) and with a fixed wing (flying wing, airplane) and are used for terrain exploration, rescue operations, in the work of fire services, military intelligence, and the like. UAV often use the first-person flight mode - First Person View (abbreviated FPV) [1], which is based on the use of a directional video camera and video transmitter. The pilot controls UAV over the air using radio remote control based on information from the heading video camera. A UAV video camera is connected to a video transmitter, which usually operates at a frequency of 5.8 GHz in real time. The image is displayed on a monitor, TV, video glasses, video helmets with which the pilot interacts. The result of development microelectronics was an increase in the zone of reliable reception radio signals for UAV control and video acquisition. Now, low-cost transceivers using transmission frequency conversion provide reliable communication at a distance of 15-20 km when flying in line of sight at an altitude of 100 m [2, 3].

At the same time, when flying through settlements over long distances, strong interference may occur, especially in video transmission. This leads to the fact that pilot loses the image of terrain and is not able to continue control the UAV. If in this case you do not use the system of automatic return to the starting point, UAV often loses control and crashes without completing its task. The return system should work in such a way that it allows the user to return manual control to the pilot using the remote control when a connection appears. The paper considers the creation of two experimental UAV video reconnaissance UAV: flying wing with wingspan of 1000 mm, fuselage length of 500 mm, and flight weight of 500 g. and quadrocopter with frame size of 250mm, weighing 400g, which can automatically return in the event of loss of radio communication with the pilot. Moreover, in both cases the installation of a magnetometer and barometer is not provided, the functions of which are performed by the GPS receiver. This leads to a simplification of the design and lower its cost. This article shows further development (2020) of the ideas team authors [1] on the use of rescue mode for UAV based on microcontrollers of the stm32 family, made in 2018 - 2019.

2 RESEARCH METHODS

As shown [1] for a stable UAV flight, especially during wind, flight along waypoints, return to the launch point in case of loss communication with the control panel and loss of video communication, automatic altitude retention, flight controller with software is used. In addition to the microcontroller, sensors such as a gyroscope and accelerometer are installed on it. For automatic flight, an additional GPS receiver is connected. The most common flight controllers are MultiWii, APM 2.x, Pixhawk, SPRacingF3, OMNIBUSF4V3, SPRacing F7 and others [2-6]. The first three use Ardupilot firmware, the rest use cleanflight, INAV, betafight firmware. Firmware - software for microcontrollers. They are based on mathematical models, such as PID controllers, Kalman filter, complimentary filter, dynamic Notch filter, etc. The listed firmware have open source code, which can be adjusted during test flight tests. Firmware customization for a specific set of flight modes, wing geometry, copter frame, propulsion system, etc. It requires the selection of a large number of parameters in order to ensure a stable flight with minimal power consumption from the battery. The aim of the work is to study possibility of constructing a flying wing based on the experimental firmware INAV [8], which will allow it to return to the starting point when performing video reconnaissance in FPV mode [7,8] without ensuring high accuracy. The accuracy should be such as to ensure that the automatic return of UAV is intercepted by control panel when restoring video communications. In this work, we also consider construction of a copter based on the flight controller OMNIBUSF4V3 [9] with firmware Betaflight [10] and GPS [4,11] by receiver, which will ensure the return of copter to radio communication zone in any emergency. This work is related to practical study of the possibility returning the copter in GPS Rescue mode [12] for Betaflight ver.4.1.1 [10] firmware, which is last and stable at the time of writing.

The main components of wing are: 2204 / kv2300 motor, 30A ESC controller, 5x4.5-inch propeller, NEO6MV2 GPS receiver based on the NEO-6M-0-001 module, microOSD, SPRacingF3 acro flight controller [13], Eachine TS832 video transmitter, course video camera Eachine 1000TVL.

The same motors and ESC are installed on the copter, but flight controller OMNIBUSF4V3 is used on which Rescue mode can be used. Both UAV are controlled by equipment - FlySky FS-i6 [14]. In [15] presents training of a deep learning convolutional neural network for gesture recognition and tracking of a quadrotor Unmanned Aerial Vehicle. The neural network was coded in Python using the Keras library and was trained on a laptop computer. Inference was performed on a Raspberry Pi 4 computer that is intended for use as a companion computer aboard a quadcopter. In [16], the results of the development of a model of the functioning of the combined correlation-extreme navigation systems of flying robots with radiometric and optoelectronic sensors were introduced. As a result, an expression is obtained for the probability of the correct location of the object binding. These models can be used to locate UAV.

The method for solving the problem is use and adjustment of INAV firmware for the flying wing and Betafligh firmware for the copter as a result of numerous test flight tests. The INAV and Betafligh firm wares are designed for flight controllers, which are based on microcontrollers of the STM32F1, STM32F3, STM32F4 and STM32F7 families.

3. THE MAIN MATERIAL AND RESULTS OF WORK

Consider setting up test model of a flying wing. To configure the flight controller operating modes, INAV configurator [11] is used. Settings are made by setting parameters in the tabs of the configurator and in command mode. Figure 1 shows a photograph of flying wing with rectangular wing shape, for which the firmware settings of INAV ver.1.7.2 are shown using the budget flight controller SPRacingF3 acro.

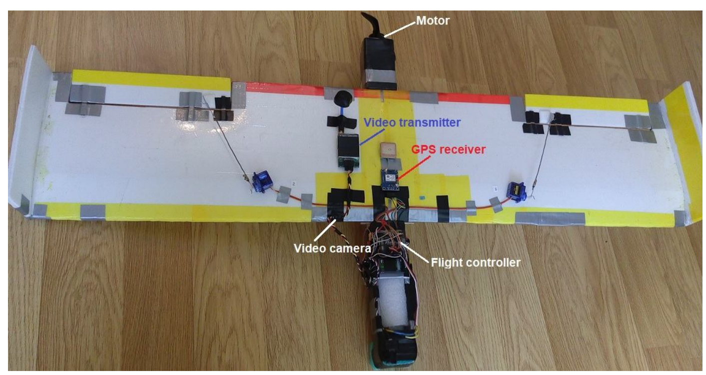

Figure 1: Photo of an experimental flying wing

In the traditional form, circuit of connection electronic components was presented in [1,4]. On it, the servo drives of the elevons wings should be connected to a separate 5V power supply. An electrolytic capacitor of 1,500 microfarads should be installed parallel to the servos reduce voltage ripples. The flight controller, control receiver, GPS receiver are connected to another 5V source integrated with ESC motor controller.

In the Ports tab of INAV configurator [4], you must configure the flight controller to work with GPS receiver via UART2 at speed of 38400bit / s. For this wing, Flysky FS-iA6 receiver is installed, connected to the flight controller via PWM, so it is possible to use only UART2 port.

In the Setup tab, accelerometer is calibrated along 6 axes according to the scheme presented in source [17].

Parameters [4] are set in the Configuration tab, which determinetype of ESC controller [1,5], taccelerometer used, protocol of operation receiver controls equipment, protocol of operation GPS receiver.

To work with the failsafe parameters,Flysky FS-iA6 receiver is pre-configured so that when the control panel is turned off, it sends a 900 μs pulse to the flight controller via throttle channel (3rd channel-gas). Such a receiver setup is presented in sources [4, 14].

Parameter settings for PID controller were carried out by sequential selection of them during test flights. Their values are chosen to ensure a stable flight of the wing. The latest versions of INAV allow automatic tuning according to a special algorithm during manual flight. However, it does not always provide the best tuning for PID controller.

In the Modes tab, some flight modes of the controller are set, which can be activated from the control panel [5]. Since the receiver used is six-channel, only two switches can be used. On first left (toggle switch is set to ANGLE flight mode for any of its positions. If you turn the toggle switch down, ANGLE mode continues to work and NAV LAUNCH (take-off assistant) is switched on additionally. The three-position toggle switch is set to hold altitude (NAV ALTHOLD) - average position of the toggle switch and return home mode) (RTH) - lower position.

The importance in the work is given to setting up and testing the functionality of failsafe mode. If it does not work if the control panel loses contact with the flying wing, then it will be lost.

Failsafe (safety) is state that the flight controller should enter if the control receiver loses communication with equipment. Any of listed INAV firmware conditions should call failsafe:
1. Any flight channel (pitch, roll, gas or yaw) does not send impulses from the control panel.
2. Any channel is out of range, which can be checked using the commands in cli tab: get rx_min_usec; get rx_max_usec, or on the failsafe tab. According to the failsafe tab rx_min_usec = 920; rx_max_usec = 2115.
3. FAILSAFE mode is activated using the switch on control panel.

If failsafe happens when the flight controller is in disarming mode (not ready for flight or not armed), this will prevent it from switching to arming (ready for flight-armed).

If failsafe occurs in arming, INAV firmware enforces the security policy that is configured in the failsafe_procedure command.
Available command options:

DROP: Turn off the motors and disarm (UAV will crash and be damaged).

SET-THR (Land): Enter a pre-set roll/pitch/yaw angle when lowering aircraft and set the throttle (gas) to a predetermined value for failsafe_throttle parameter for a predetermined time specified by the failsafe_off_delay parameter (20sec by default). This is intended to make UAV relatively safe landing. In this case, a gyroscope and an accelerometer are used.

RTH: (Return to start point). The INAV firmware allows UAV to automatically move back to its original position and land or circle within a radius of 50 m above the landing site for aircraft. A GPS receiver is used for this.

NONE: Do nothing. This is intended for a fully automated flight, for example on waypoints outside radio range from the control panel. This parameter is very unsafe during manual control of UAV.Parameters are set in the CLI and Failsafe tabs.

To obtain telemetric data from UAV, microSD is used in work [17]. For its firmware, Arduino IDE programming environment and a set of MWOS programs are used [18]. This will allow you to impose telemetry data on the image of the heading camera. For microOSD firmware, USB to TTL converter is used, which connects to USB output of the computer and to UART input of microOSD board based on CH340 chip. The work describes in detail microOSD programming procedure and its setting for displaying the specified telemetry parameters on monitor screen. Using this OSD, you can not only display telemetry parameters, but also change the parameters of flight controller, for example, the parameters of PID controller. To do this, on the control panel, you need to move left stick to the center and to right, right stick up. By manipulating sticks, displayed parameters are changed and next pages with other parameters are navigated.

Figure 2 shows a typical connection of heading camcorder, video transmitter, and microOSD to SPRacing F3 acro flight controller via the UART1 port [1]. When connected to a computer for configuration through INAV configurator, microOSD board disconnected from the flight controller. It is important to note that flight controller and microOSD +

camera + video transmitter must be connected to different 5V power sources.

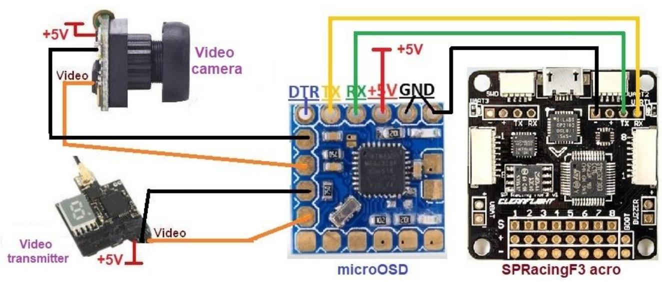

Figure 2: Typical OSD connection to the flight controller

Consider the configuration of UAV - quadrocopter. Unlike INAV firmware, which uses failsafe return mode, Betaflight firmware uses Rescue mode. A feature of this mode is the quadrocopter return only in presence of a GPS receiver. Sewing INAV in the case of a quadrocopter requires a barometer and magnetometer, which complicates the design.

This paper discusses GPS Rescue testing for version 4.1.1. GPS Rescue is not a complete “Return to home” (RTH) feature. This mode is not intended to be an instrument for independent flight of a quadrocopter, and it is not used for these purposes. GPS Rescue does not have the ability to automatically land, and it intentionally controls the “soft fall of the copter” when it approaches its starting point. The purpose of the mode is to return copter closer to starting point so that UAV pilot can resume control in case of signal loss. The pilot should resume monitoring as soon as possible and prevent GPS Rescue from landing the copter, as it may break it. The presented work is related to the construction of a quadrocopter and its configuration for testing this mode in order to conclude the suitability for a reliable return to reliable radio communication zone with the subsequent “soft” landing of the copter in manual mode.

To implement this mode, the following requirements must be met:
- availability of GPS receiver. We used the NEO-6M-0-001 module, which supports simultaneous operation with one of GNSS systems (satellite navigation system) and therefore establishes communication with fewer satellites (6-11). At present, two satellite navigation systems are really globally working: GLONASS and GPS.
- accelerometer must be turned on, the rescue mode requires that quadrocopter is aligned.
- barometer for operating the mode is not mandatory, but if it is installed on the flight controller, then it is advisable to turn it on. It is also convenient to use in case of output to monitor screen in flight mode using FPV telemetry data. For example
- a more accurate value of the flight altitude and the speed of rise and fall compared with GPS receiver.
- this mode does not require a magnetometer, however, it will be used during its installation.
- if the 3D function is enabled in firmware, GPS Rescue mode will be disabled. 3D provides for the flight of copter "upside down" to perform aerobatic tricks with the rapid passage of complex obstacles. In this case, the orientation of GPS antenna changes and satellite loss is possible, which will cause the motors to turn off and the copter to fall.

In operation, GPS Rescue mode is installed on a specific experimental copter, which uses FPV camera, video transmitter, GPS receiver, flight controller with a barometer and, necessarily, OSD chip supported by betaflight ver.4.1.1 firmware for flights. In figure 3. photo of this quadrocopter is shown on ZMR250 frame.

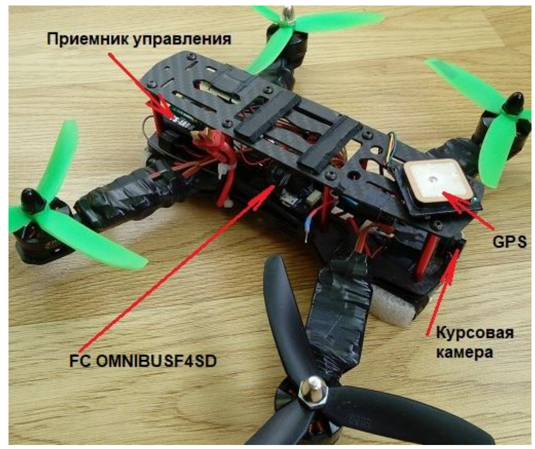

Figure 3: Photo of an experimental quadrocopter

In figure 4 shows a schematic interaction of the basic elements quadrocopter based on the flight controller OMNIBUSF4V3. It should be noted that a video transmitter with heading camera must be connected to the battery through a separate voltage converter, for example at 5V. This is due to the high current consumption during operation of video transmitter.

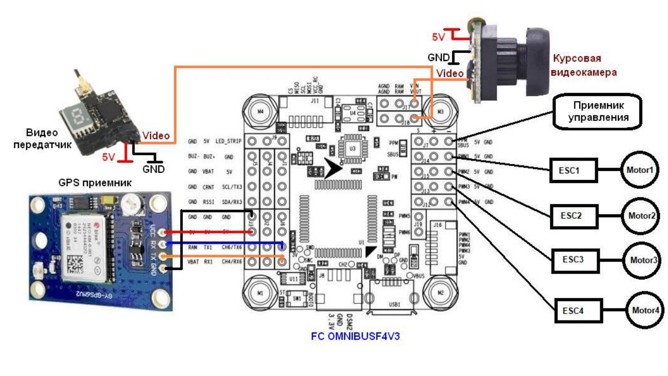

Figure 4: Interaction of main elements tested quadrocopter

The following is the configuration of main parameters electronic components of the investigated quadrocopter in betaflight ver configurator. 10.6.0.

In the "Ports" tab, you need to configure the flight controller to work with GPS receiver via UART6. Since the control receiver is in PPM mode, nothing is configured in this tab. In "Configuration" tab, the parameters shown in figure 5 are set.

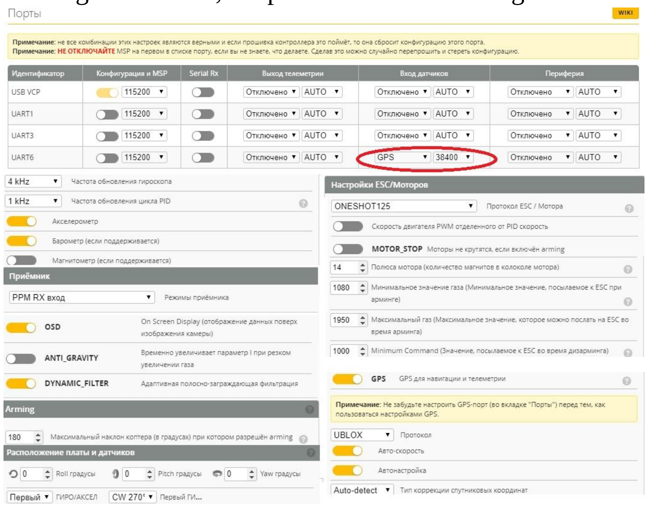

Figure 5: Settings for 'Configuration' tab

The OMNIBUSF4V3 flight controller has an OSD chip AT7456. Therefore, OSD configuration is simpler than for SPRacingF3 controller. To do this, in betaflight configurator, in OSD tab, the necessary parameters are set, which should be displayed on the video receiver screen for FPV flights (figure 6).

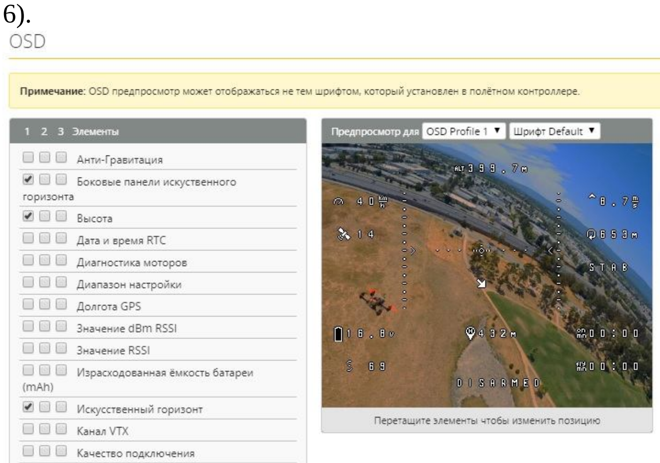

Figure 6: OSD setup

The displayed parameters are selected from table on the left. In the work, the side panels of artificial horizon were displayed, flight altitude, artificial horizon, home arrow (required for GPS Rescue mode), battery voltage, gas damper percentage, flight sight, distance to take-off point, total distance traveled, flight mode (Acro , Horizon), altitude change rate, GPS speed, number of satellites caught, battery and flight time, Disarmed. Changing the placement of selected parameters on the screen is done by dragging them with mouse. If there are a lot of parameters so that they do not interfere with video viewing, they can be placed in other profiles, which are presented in table on the left as 1,2,3. OSD Betaflight also has the ability to enter the built-in menu to change, for example, the parameters of PID controller. To do this, on the control equipment, right stick deviates all way up, and t left one briefly from the middle position to the left. After that, a new menu for tinctures appears, to enter each submenu and also to change the parameter. To change a parameter (for example, PID controller), you need to briefly deviate the right stick to the left. Work with OSD menu is only possible in Disarm mode (not in flight).

In figure 7 shows examples of how a customized OSD works. The first two photos are presented with a closed camera lens. They display parameters during flight and after landing. The third photo displays the parameters of PID controller after entering the built-in menu for setting parameters. Here camera lens is in open state - OSD parameters are superimposed on the video image.

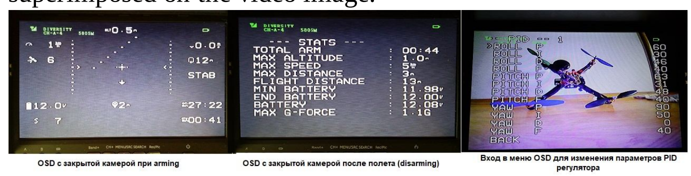

Figure 7: An example of result configured OSD

Consider setting GPS Rescue mode. To do this, use cli tab in which the commands are written, purpose of which with their parameters are listed below.
set failsafe_procedure = GPS-RESCUE.

This sets the GPS Rescue procedure for failsfe.
set gps_rescue_initial_alt = [number] (default is 50)

When Rescue Mode is activated - for example, with the AUX4 switch on the control panel, quadrocopter will turn its front towards launch and try to rise safe height relative to take-off point. This altitude will be either the corresponding number parameter or maximum altitude recorded during the flight +15 m, whichever is greater. The default height is 50 meters.
set gps_rescue_ground_speed = 800 (default is 2000).

This is the speed with which quadrocopter will try to return, in centimeters per second. The speed is set at 8 m/s (about 30 km per hour).
set gps_rescue_angle = 32 (default is 32).

Sets maximum allowable tilt angle of when returning to the launch point. This parameter may prevent the achievement of full speed (8 m/s) if its value is too small. The higher angle, more difficult it is for the height adjuster to maintain a stable height [19]. When there is a chance of returning in the headwind, this parameter can be increased to 45 degrees.
set gps_rescue_descent_dist = 100 (default is 200)

This is the distance in meters at which quadrocopter will begin to decline from the take-off point from height specified

by the set gps_rescue_initial_alt command. The main thing is that within this distance there should be no obstacles to decline (for example, trees, hills, buildings).
set gps_rescue_min_dth = <meters> (default is 100)

The command sets the minimum distance in meters from the take-off point, starting from which GPS Rescue mode will work. If you activate the mode closer than this distance, copter will fall. A value of less than 100 meters is not recommended, since closer than 100 meters may not work.
set gps_rescue_ascend_rate = 300 (default is 500) (added in betaflight 4.1)

This sets the vertical speed at which quadrocopter will rise when returning to the launch point, expressed in centimeters per second (set to 3 m / s).
set gps_rescue_descend_rate = 150 (default is 150) (added in betaflight 4.1)

This is the vertical speed at which quadrocopter will descend to the starting point, expressed in centimeters per second.

Setting throttle parameters by commands
set gps_rescue_throttle_min = 1100 and set gps_rescue_throttle_max = 1600 refers to versions of betaflight older than 4.1. For example, the first parameter determined speed of rotation motors during landing, and second - at maximum speed of rise and return to the launch point. In version 4.1 and newer, this is a range of engine speeds that is not exceeded in GPS Rescue mode, since the GPS Rescue lift and landing speeds are set by the previous parameters. However, developers recommend testing for these newly assembled copters for these parameters.
gps_rescue_alt_mode = [MAX_ALT, FIXED_ALT, CURRENT_ALT] (added in betaflight 4.1).

This command with the listed parameters allows you to set the flight altitude of copter in GPS Rescue mode.
MAX_ALT - for this parameter, the return height will correspond to the height set by the set gps_rescue_initial_alt = 50 (50m) command, or the maximum height recorded during the flight +15 m, whichever is greater.
FIXED_ALT - here quadrocopter will return to the take-off point at the height set by gps_rescue_initial_alt = 50 (50m) command.
CURRENT_ALT - quadrocopter will return at the height that was set during activation of rescue mode (GPS Rescue).

For GPS Rescue mode to work, you must set the minimum number of satellites with which GPS receiver must communicate:
set gps_rescue_min_sats = 6 (default is 8).

In order to check the operability of GPS Rescue mode, the reliability of its operation, for a built quadrocopter with firmware version 4.1.1. The sequence of procedures presented below was performed.

The span was performed on quadrocopter at a distance of more than 100 meters from the distance indicated in set gps_rescue_min_dth = 100 command. Here, the start of the operation GPS rescue mode is indicated at a distance of 100 m from the start point. Therefore, we fly over a distance of about 150m. When flying in a straight line, the home arrow should point in direction oa launch point. OSD is pre-configured on the copter. If the arrow indicates a different direction, Rescue mode is not activated, for example, with the toggle switch from the remote control. After activating GPS Rescue, if configured correctly, the copter will fly in direction of arrow. When approaching the start point and beginning of the decline in order to prevent a crash, GPS Rescue mode was deactivated by a switch on the toggle switch. The control went into manual mode, in which quadrocopter was landing.

The set failsafe_procedure = GPS-RESCUE command (indicated earlier) activates GPS Rescue mode in case of loss communication with the control equipment. In the event of a return radio communication, control of the aircraft will be returned to the control panel. However, this is not always convenient, since the copter in this case may be outside the scope of visibility or video communication. Therefore, the further route of its flight may not be determined. In the event of a communication failure during tests on the control panel of toggle switch, GPS rescue mode was activated and even after the radio connection with remote control was established, the copter would continue to follow to start point. After the appearance of video communication (FPV flight) or visual detection of the copter by a toggle switch, GPS Rescue mode was turned off, followed by landing or continued flight (on heading camera) in manual mode.

When using GPS rescue, the command to enable the health check of this mode was used:
set gps_rescue_sanity_checks = RESCUE_SANITY_ON.

This check ensures that:
- permanent connection of GPS receiver to the flight controller
- GPS receiver sends the actual GPS Fix value to the flight controller
- quadrocopter did not experience strong vibrations (for example, hitting an obstacle)
- number of satellites with which communication is equal to or more gps_min_sats
- quadrocopter approaches the take-off point after reaching the specified altitude in GPS Rescue mode

If any of these conditions is not fulfilled, the motors are switched off (disarming). The last two conditions have a delay of several seconds before being triggered.

When starting the copter, following was taken into account. Arming a copter is impossible without GPS Fix if GPS Rescue mode is configured (even if it is off on the control panel). For a flight without GPS Fix in an area with poor satellite coverage, GPS Rescue mode is deactivated using the command:

```
set gps_rescue_allow_arming_without_fix = ON
```

GPS Rescue will be unavailable during flight and a warning (RESCUE OFF) will appear on OSD when OSD is running. If the proper number of satellites is received during the flight, a landing, disarming and arming procedures are performed to enable GPS Rescue.

4. CONCLUSION

Based on test flight tests:

1. It has been established that in case of loss video communication with UAV during FPV flight, the pilot completely loses orientation in terrain. Switching the flight controller to NAV RTH (wing) or GPS Rescue (copter) mode reliably returns the device to launch zone, which, when establishing a video connection, allows the pilot to switch back to manual control from the remote control.

2. The possibility of reliable automatic return to the starting point using only GPS receiver for UAV of a rotor type and with a fixed wing, in which an magnetometer and a barometer were previously used for this purpose, is shown. This led to a simplification of the design and lowering its cost.

3. It is noted that an important condition for the return is stable connection of GPS receiver with the number of satellites not less than those set in the corresponding parameters. Moreover, in case of communication failure, the flying wing can continue a relatively long flight along a given route until communication is restored. Quadrocopter in case of loss communication after a short period of time (1-2 sec.) Turns off the motors and performs a hard landing.

4. For stable operation of GPS Rescue mode, the copter during flight should use the stabilization mode (Angle) with accelerometer turned on, fly with small tilt angles and in cloudy weather. It was found that greater angle of inclination of the copter, smaller the number of satellites GPS receiver catches. Therefore, GPS Rescue mode is not advisable to use in Acro, 3D, Horizon flight modes and when making flip-s.

5. It has been practically established that GPS Rescue mode is more appropriate to use in the event of a video communication loss with the heading camera (FPV flights) while maintaining communication with the control panel. To return to video communication zone on the control panel, stabilization mode (angle) is set and GPS Rescue mode is turned on. When establishing a video connection, determining location by the pilot, GPS Rescue mode is disabled from the remote control and the copter can continue flying via FPV.

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