Design of a quadrocopter with PID-controlled fail-safe algorithm

Oleg V. Baranov*, Nikolay V. Smirnov, Tatyana E. Smirnova, and Yefim V. Zholobov
St. Petersburg State University, Peterhof, St. Petersburg 198504 Russia
{o.baranov, n.v.smirnov, t.smirnova}@spbu.ru, st062550@student.spbu.ru

Received: February 20, 2020; Accepted: June 2, 2020; Published: June 30, 2020

Abstract

Unmanned aerial vehicles (UAV) are used in various fields of human activity. Unfortunately, they often fall into various emergency situations. In special cases (expensive equipment on board the copter, important information, etc.) it is important to provide a fail-safe landing. In this article, we consider two problems. First of all, we propose an approach of choosing a hardware configuration of a quadrocopter, which provide a possibility to solve emergency landing problems. The main target performance characteristics for such a device are substantiated. The calculation methodology takes into account the choice of commercially available components with the required characteristics. To realize this approach, the eCalc software was used. The second problem considered in this article is a control problem of automatic emergency landing with only two of four engines working. For this purpose, we propose a mathematical model describing the quadrocopter movement in emergency situations. This model use a PID controller to control the working engines. Numerical experiment is carried out to prove the efficiency of this approach. For implementation the MATLAB package was used.

Keywords: quadrocopter, UAV, fail-safe, control

1 Introduction

Unmanned aerial vehicles (UAV) of helicopter type: quadro- hexa- and octocopters have become widespread in various fields of human activity (reconnaissance, surveillance, transportation, etc.). Nowadays, there is certain research interest in problems and related applications that using multiple quadrocopters [1,2]. At the same time, the probability of accidents increases significantly and this forces researchers to solve additional control problems to avoid collisions [3]. Moreover, according to statistics, accidents of UAV occur hundreds times more often than accidents of manned vehicles [4]. The main causes of failures are malfunctions in the control system, which includes a number of high-sensitivity sensors, as well as various mechanical damages [5–8]. Obviously, the most dangerous situation is the failure of one or several motors directly in flight, regardless of the failure nature (a failure in the control or power plant, a mechanical frame damage or a propeller destruction). In this case, with respect to multirotor systems, the failure situation of all electric motors simultaneously is less likely, and hence the planting possibility remains even for a scheme with four screws – a quadrocopter. Mathematical modeling shows [5,7,9–11] that even with the loss of two diagonal propellers out of four, the device landing is possible, albeit with loss of control over one of the degrees of freedom. However, in practice, for the successful realization of such a landing, already during the device design, it is necessary to provide some solutions to ensure the power reserve of the engine-propeller unit. This necessarily leads to a loss of the overall efficiency

Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications (JoWUA), 11(2):23-33, June 2020
DOI:*10.22667/JOWUA.2020.06.30.023*

*Corresponding author: D. 27, ul. Tsentral'naya, d. Gostilitsy, Lomonosovskiy r-n, obl. Leningradskaya, 188520, Russian Federation, Tel: +7-904-602-03-99

of the system and the question of calculating the UAV performance characteristics for such a device is especially important, because in addition to reliability, any UAV must have the necessary operational characteristics.

In this article, we propose an approach to choosing a hardware configuration of a quadrocopter, which provide a solution to emergency landing problems. Based on a special mathematical model, we develop algorithms and software to control UAV in emergency situations. Numerical experiment is carried out to prove the efficiency of the approach.

In continuation of the previously performed work [11], this article proposes the calculation of the hardware configuration for a device with another, more popular and small frame size of 350 mm (diameter 700 mm), as well as a new approach to control running engines by PID controller. Using a PID controller for direct control of angular velocities of two working engines makes possible an emergency landing in a fully automatic mode, with no operator control.

2 Requirements for the fail-safe configuration

If two of the four motors of the quadrocopter fail, successful landing requires that the thrust of the two remaining engines reaches one equipped mass of the vehicle. However, taking into account:

- an unfavorable mode of movement during an emergency landing (constant rotation);
- system efficiency;
- a probable unfavorable external situation (weather, electromagnetic, etc.);

for a fail-safe configuration, it makes sense to have a two-engine power-to-weight ratio comparable to the typical for the full thrust-to-weight ratio of the usual configuration, i.e. not less than 1.75 equipped masses of the vehicle [12]. Thus, the target indicator of the full thrust-to-weight ratio of the fail-safe quadrocopter configuration is proposed to be installed in the range of 3.5 – 5 equipped masses of the vehicle

In order to achieve this indicator, when designing the quadrocopter configuration, the following components are selected:

- a power source (in this work we will consider lithium-polymer batteries, as the most common power source for quadrocopters);
- electronic speed controllers (ESC) (one regulator for each motor);
- power electrical wires; electric motors and propellers.

The increase of thrust-to-weight ratio leads to an increase in the weight of these components. Also, providing a large thrust leads to a design load index, which provides a stationary hovering of the vehicle, from an optimal range.

Now we define the main target performance characteristics of the fail-safe configuration that meet the specified requirements. They are presented in Table 1.

Note that requirements No. 2, 3, 7 (see Table 1) for the fail-safe configuration are reduced relative to typical requirements for general-purpose quadrocopters. A critically low index No. 5 is explained by the high thrust-to-weight ratio. It has no fundamental significance, because the maximum thrust mode of all four motors with a total thrust-to-weight ratio close to 5 equipped masses is a mode that does not have a typical practical application.

Table 1: Main target performance characteristics of the fail-safe configuration

No.	Characteristic	Value
1	Trust-to-weight ratio	3.5 – 5 equipped masses
2	Hover flight time	more 15 min
3	Specific thrust	more 5 g/W
4	Battery load	less 50 C (C – battery capacity)
5	Minimum flight time (all motors on max)	more 2 min
6	Hover flight throttle	20 – 40%
7	Hover flight efficiency	more 70%
8	Optimal horizontal speed	more 25 km/h

Table 2: Main target performance characteristics

No.	Characteristic	Value
1	Number of blades for each propeller	2
2	Field elevation	100 m ASL
3	Pressure (QNH)	1013 hPa
4	Battery type	LiPo
5	Maximum discharge	90%
6	FCU Tilt limit	none
7	Gear ratio	1:1
8	Additional electrical load	0 W

As the key performance characteristics, we consider the time and distance of the flight, depending on the motion speed. The selection of components is carried out in order to maximize the key performance characteristics.

To calculate the performance characteristics, we also fix the general parameters of the vehicle configuration and the state of the external environment (see Table 2).

3 Calculation of the performance characteristics

Calculation of performance characteristics is carried out for a quadrocopter with a 350 mm frame size. For calculations with parameters of Tables 1, 2, the eCalc software was used (see xCopterCalc [12]). The calculation methodology assumes the selection of commercially available components with the appropriate characteristics to guarantee the target performance characteristics. xCopterCalc contains a continuously updated database of components for multirotor systems. In the absence of a suitable part in the database, xCopterCalc allows you to add the original by entering its characteristics. Thus, with this software it is possible to calculate almost any configuration of a multirotor system, receiving as a result not only the vehicle performance characteristics, but also a draft list of components for subsequent assembly.

The calculations results of the fail-safe configuration are presented in Table 3.

The fail-safe configuration of a quadrocopter has even more technical peculiarities, but such a device has high performance characteristics No. 9, 14, 15 (see Table 3). The dependence of the engine-propeller combination characteristics on the motor current is shown in Fig. 1.

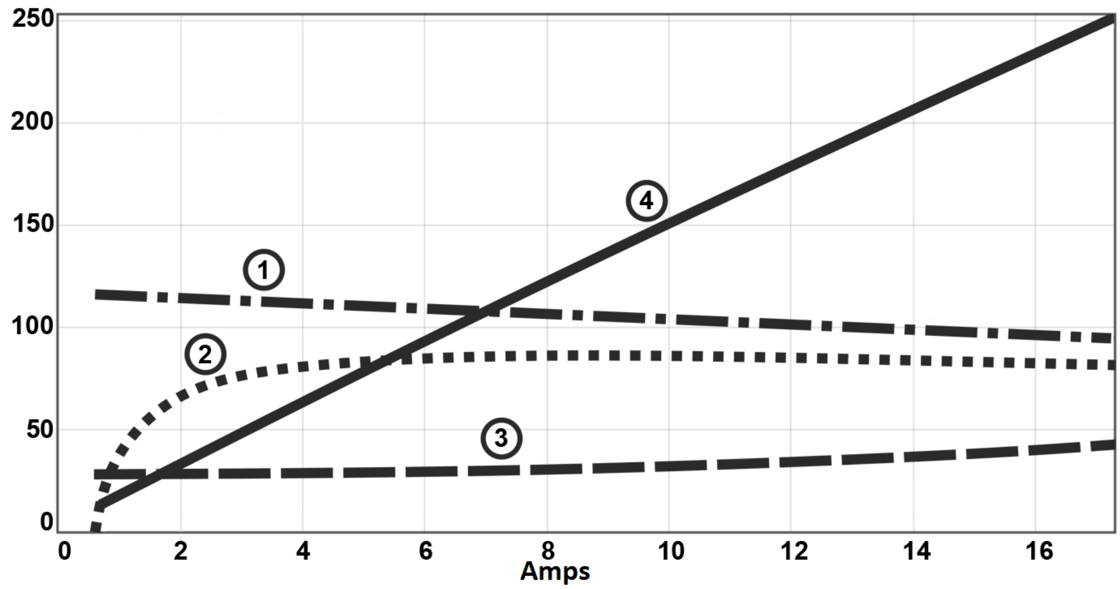

Figure 1: Dependence of the power plant characteristics on the electric motor current. Curve 1 – power (W); 2 – efficiency (%); 3 – max. rev. (×100 rpm); 4 – motor temperature (°C)

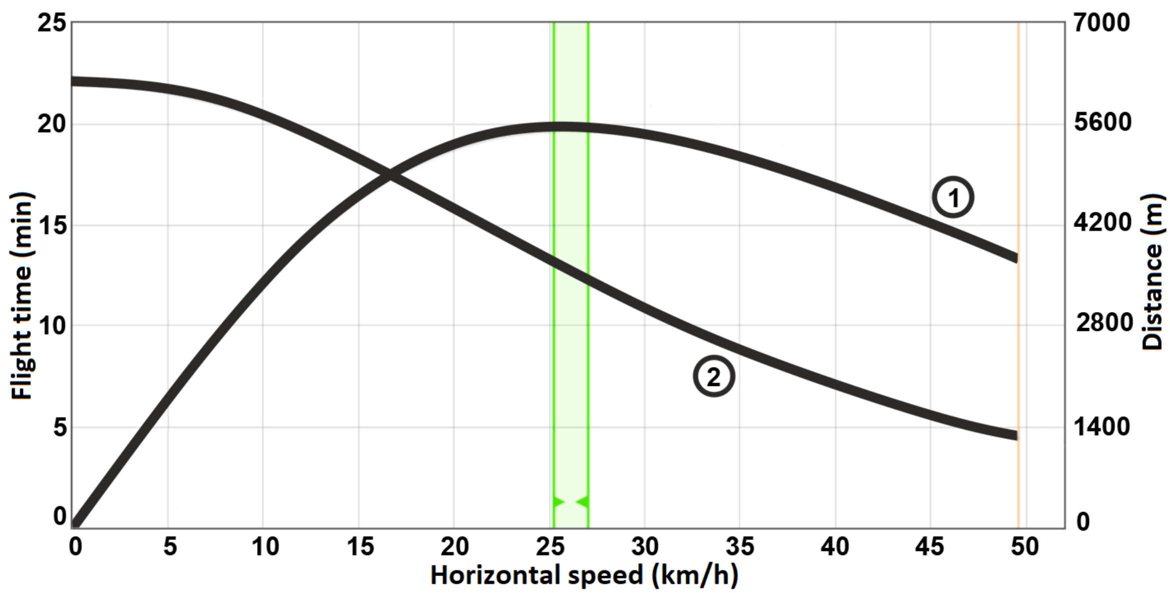

Figure 2: Dependence of the distance (curve 1) and the flight time (curve 2) from the speed

Table 3: Fail-safe configuration parameters

No.	Characteristic	Value
1	Battery capacity – nominal/maximum discharge current (by battery design)	3 Ah – 65/100 C
2	Stored energy	44.4 Wh
3	Cell configuration (S – serial, P – parallel cell connection)	4S1P
4	Battery load	19.03 C
5	On load battery voltage	14.84 V
6	Battery nominal voltage	14.8 V
7	Specific thrust	8.43 g/W
8	Minimum flight time	2.8 min
9	Hover flight time	19.9 min
10	Motor model	Turnigy Multistar Elite 2810-750
11	Trust-to-weight ratio	3.6
12	All-up weight	1.006 Kg
13	Drive weight	0.726 Kg
14	Maximum horizontal speed	54 km/h
15	Rate of climb	11.5 m/s
16	Hover flight throttle (linear)	42%
17	Efficiency (hover)	83.9%
18	Motor current (hover)	1.92 A
19	Motor current (maximum)	14.27 A
20	Max ESC current	20 A
21	Efficiency (100% throttle)	85.1%

The key performance characteristics are shown in Fig. 2. The horizontal speed range (optimum in power consumption) is 25-27 km/h. The maximum flight distance is 5.6 km.

4 Modeling of emergency situations

A quadrocopter movement can be described by the differential equations system [11]

$$\begin{cases} \dot{x} = V_x, \quad \dot{y} = V_y, \quad \dot{y} = V_z, \quad \dot{\varphi} = \omega_\varphi, \quad \dot{\theta} = \omega_\theta, \quad \dot{\psi} = \omega_\psi, \\ m\dot{V}_x = (\sin\psi\sin\varphi + \cos\psi\sin\theta\cos\varphi)U_1, \\ m\dot{V}_y = (-\cos\psi\sin\varphi + \sin\psi\sin\theta\cos\varphi)U_1, \quad m\dot{V}_z = U_1\cos\theta\cos\varphi - mg, \\ I_{xx}\dot{\omega}_\varphi = (I_{yy} - I_{zz})\omega_\theta\omega_\psi - J_{TP}\omega_\theta\Omega + U_2, \\ I_{yy}\dot{\omega}_\theta = (I_{zz} - I_{xx})\omega_\psi\omega_\varphi + J_{TP}\omega_\varphi\Omega + U_3, \quad I_{zz}\dot{\omega}_\psi = (I_{xx} - I_{yy})\omega_\psi\omega_\theta + U_4, \end{cases} \tag{1}$$

where x, y, z are coordinates of the mass center; V_x, V_y, V_z are velocity projections; φ, θ, ψ are the roll, pitch and yaw angles; ω_φ, ω_θ, ω_ψ are corresponding angular velocities; m is the quadrocopter mass; I_{xx}, I_{yy}, I_{zz} are inertia moments around coordinate axes; U_1, U_2, U_3, U_4 are control channels; Ω is the total velocity of four screws; J_{TP} is the total rotational moment of inertia around the screw axis: $J_{TP} =$

$J_P + \eta N^2 J_M$, J_P is the motor inertia moment , J_M is the propeller inertia moment, N is the gear ratio, η is the gear efficiency.

Relations between controls U_1, U_2, U_3, U_4 and angular velocities Ω_1, Ω_2, Ω_3, Ω_4, where $\Omega = -\Omega_1 + \Omega_2 - \Omega_3 + \Omega_4$, have the form

$$\begin{gathered} U_1 = b(\Omega_1^2 + \Omega_2^2 + \Omega_3^2 + \Omega_4^2), \quad U_4 = d(-\Omega_1^2 + \Omega_2^2 - \Omega_3^2 + \Omega_4^2), \\ U_2 = lb(-\Omega_2^2 + \Omega_4^2), \quad U_3 = lb(-\Omega_1^2 + \Omega_3^2). \end{gathered} \tag{2}$$

In (2) l, b and d are positive parameters [11].

Within this model, an emergency situation involving damages of one or several screws can be represented as an instantaneous change in corresponding Ω_i, i.e. $\overline{\Omega}_i = \Omega_i - \varepsilon_i$, where ε_i are losses. At the full screw destruction $\varepsilon_i = \Omega_i$ and $\overline{\Omega}_i = 0$. Substitution of emergency values $\overline{\Omega}_i$ into expressions for controls (2) and further into system (1) will determine the mathematical model of an emergency situation. The equation of the output signal of the PID controller is [9]

$$u(t) = P + I + D = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de}{dt}. \tag{3}$$

5 Numerical example

In this section we demonstrate the possibilities of the proposed approach. Using MATLAB, we developed a software package that allows simulating emergency situations and solving control problems in order to minimize consequences of emergencies.

Consider an emergency situation — loss of trust on two diagonally located screws (an accident with one screw turned off can also be considered as indicated above, forcibly shutting down the engine diagonal to the fail one). In model (1), such a failure corresponds to zeroing a pair of angular velocities Ω. As shown earlier [5], for quadrocopter with the appropriate hardware configuration, such a situation can maintain controllability in the sense of altitude control, with loss of control over the angle of rotation.

Consider the problem of automatic emergency landing in these conditions. To control the working engines of the device for landing, we will use a PID controller with switchable parameters:

1) In the reduction section ($t \in [t_1, t_2]$), the PID controller has a set of parameters for stabilizing the vertical speed to a predetermined value;

2) In the braking area ($t \in [t_3, t_4]$), the PID controller has a set of parameters for minimize the vertical speed at the moment of touching the ground ($z' = 0$ at $z = 0$)

Consider an example for vehicle with parameters: $m = 1$ kg, $l = 0.350$ m, $b = 26.5 \cdot 10^{-6}$ H·s^2, $d = 0.6 \cdot 10^{-6}$ H·ms^2, $I_{xx} = I_{yy} = I_{zz} = 0.1$ H·ms^2, $J_{TP} = 0.005$ H·ms^2.

Suppose that a quadrocopter performs a certain maneuver – a turn in a given direction. At the time $t = 5$ sec, an accident occurs and the value of Ω_2 drops to zero due to a screw breakage (see Fig. 3).

If we do nothing, the quadcopter crashes with vertical speed 87 m/s at $Z = 0$ (see Fig. 4).

The algorithm assumes automatic switching from the normal to the emergency control mode by analyzing the data from gyroscopes, accelerometers and speed of the screws rotation. This is possible because in the case of a screw breaking without failure of the electrical part, the angular velocity of the fail screw will increase significantly. Otherwise, in case of failure of the electrical part, the screw speed will decrease significantly. In both cases, an abrupt change of the propeller rotation speed will be not typical for normal flight mode, since affects only one screw and causes the vehicle to rotate. The presence of these signs can be detected with high accuracy in no more than 0.5 sec.

Further the device control goes into emergency mode. Consider the case of an emergency with the same parameters of vehicle and $PID = [50; 8; 20]$. Height of transition to the braking section $z_0 = 5m$.

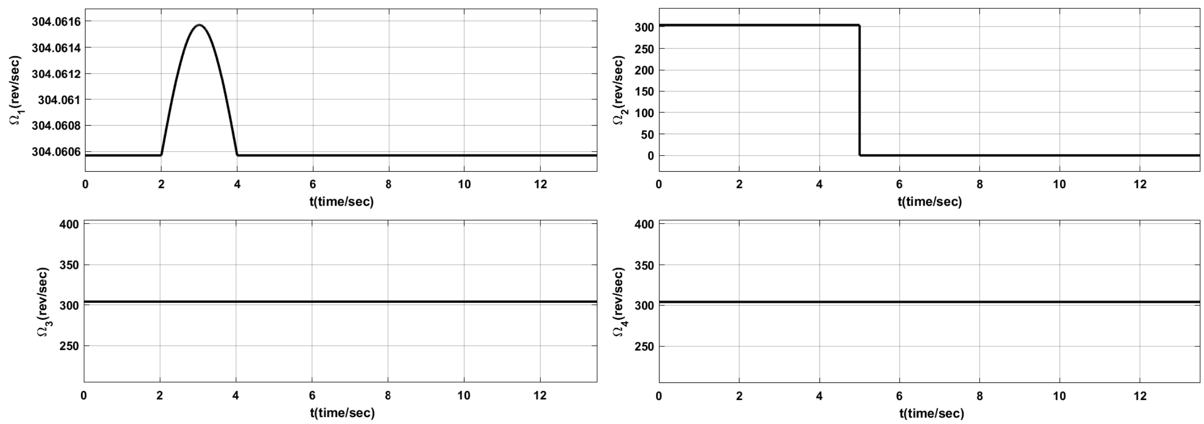

Figure 3: Emergency situation: while turning, Ω_2 drops to zero at $t = 5$ sec

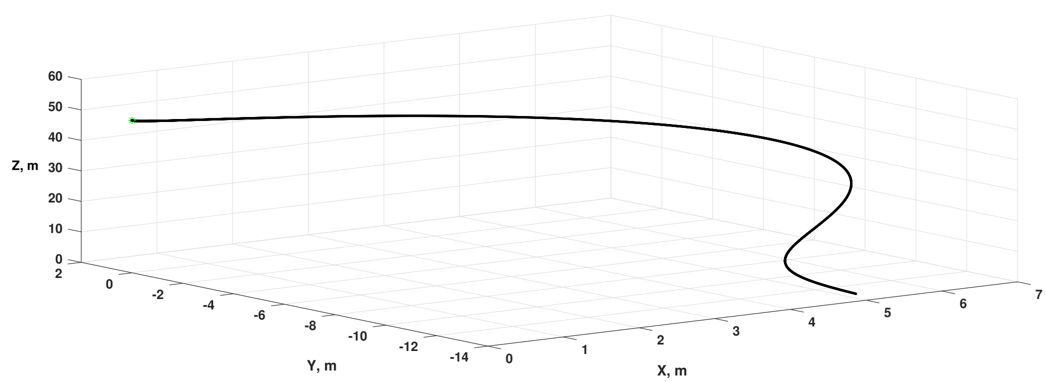

Figure 4: Emergency landing

The rotation speed of the working screws can be controlled by two PID controllers. The first one provides a pre-set vertical speed on the interval $t \in [5.5, 29.3]$ (see Fig. 5), and the second reduces the vertical speed to zero when the quadcopter approaches the landing surface (when the current height $z < z_0 = 5m$).

As a result, we have a safe landing (see Fig. 6) with zero vertical speed at $Z = 0$.

At $t = 50$ and $Z = 0.09$, we have $V_z = -0.01$ (see Fig. 7).

Thus, by using the double inclusion of the PID controller: one to stabilize the rate of descent and the second to finalize it to zero, we got a safe landing for the device with only two working motors. The effect of each application of the PID controller on the corresponding characteristics can be seen in figure 5 (see Ω_1 and Ω_2), figure 6 and 7. The first controller worked at $t \in [5.5, 29.3]$ and the second one at $t \in [29.4, 50]$.

It should be noted that the operation of the algorithm would be impossible if we ignore the recommendations for the quadcopter configuration proposed in section 2, 3.

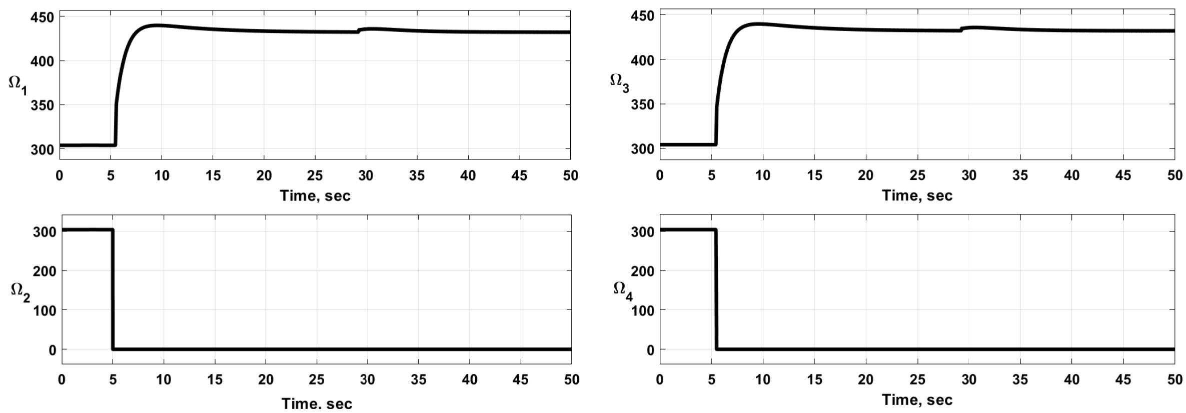

Figure 5: Fail-safe strategy

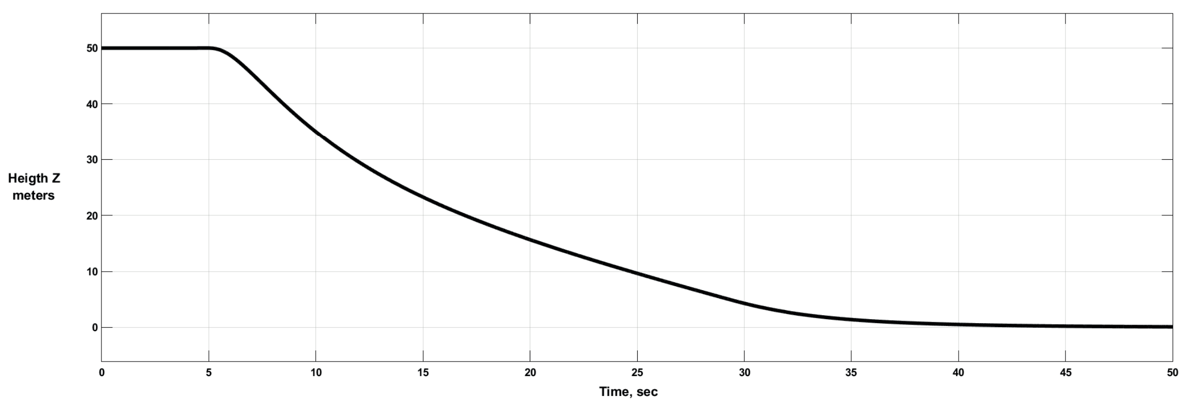

Figure 6: Fail-safe landing: Height Z

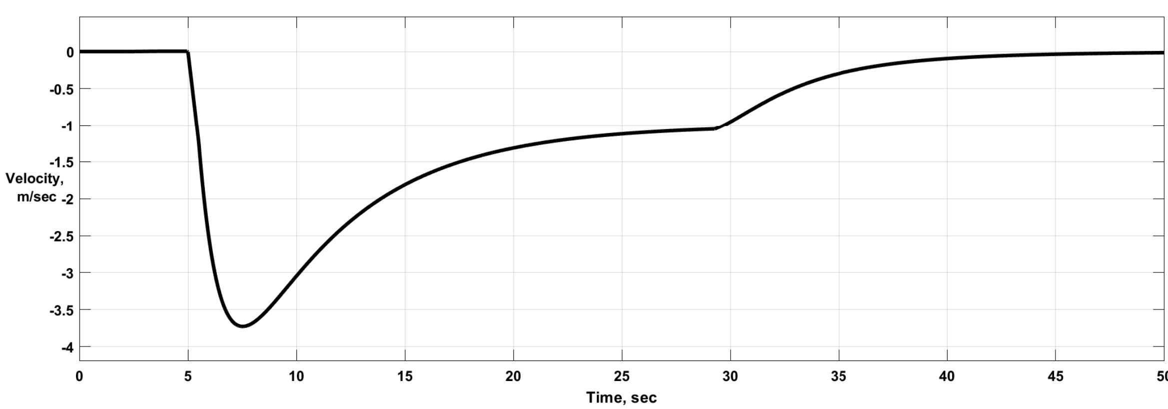

Figure 7: Fail-safe landing: Velocity

6 Conclusion

According to the xCopterCalc documentation [12], it is not directly intended to calculate the fail-safe configuration. However, due to its versatility and flexibility, xCopterCalc allows not only to obtain the value of the possible target characteristics, but also by selecting specific components, to determine all the performance characteristics and many auxiliary parameters of a specific configuration. This approach is constructive, and allows us to define the configuration features in details at the initial stage of design. The target characteristics proposed in the present work for the fail-safe configuration are achievable with the use of serially produced components. The hardware configuration proposed in the article uses components with an open architecture and can be used with popular UAV platforms, like ArduPilot Mega ver. 2.6 controller configured by Mission Planner software [13]. And although the creation of a safety factor for a fail-safe configuration is accompanied by some negative consequences (weight increase, suboptimal operation of electric motors in the hovering mode), the flight characteristics obtained as a result of the calculation allow the vehicle to be used for their main purpose. Presented in this paper, an automatic landing algorithm using PID controller is a particular interest for further study and in hardware implementation. The parameters of the controller, given in this paper may be different for a vehicle with a different mass, thrust, and geometric parameters. The approach to rescue the apparatus proposed in this work is more flexible than, for example, the installation of an additional safety parachute [14]. When using a parachute, it is impossible to control the rate of descent, as well as safety parachute systems have restrictions on the minimum height for it operation. (Note, that nothing prevents equipping the device, designed as shown in this paper, with an additional parachute). It also makes sense to equip the vehicle with additional fail-safe navigation systems [15, 16] to avoid accidents described in this paper, if possible. Noteworthy is the approach using devices with more than four rotors (for example, hexarotors). In a certain configuration, such apparats completely maintain controllability in case of loss of one engine [17]. But such devices, as a rule, belong to the heavy class and are expensive. The current trend in UAV use - is to use of many inexpensive and simple devices instead of one complex one. Presented in this paper example of a device with a frame size of 350 mm can be such an simple vehicle with additional fail-safe config. Also, the proposed approach can be used not only on the newly created vehicle, but also on an existing heavy class quadcopter by integrating proposed algorithm in a control system. The main requirement for this is to dismiss the parameters of Table 1, especially the Trust-to-weight ratio. Note also that the vehicle with a fail-safe configuration can be used as an ordinary heavy-class device, taking on extra weight and losing fail-safe capability. In this case, it makes sense to equip such an apparatus with known rescue systems, for example, with an emergency parachute. Such save method does not require engines with excess power, but also has a number of disadvantages compared with the proposed approach. For example, it is necessary to have sufficient height of flight, the inability to control a vertical speed and less reliability, because parachute lines can be tangled in screws. Future research directions are related to solving parametric optimization problems in emergency situations, as well as with a complete classification of such tasks. To solve them, the adaptive method of optimal control (Gabasov's method [18]) is of particular importance. This method has been successfully applied in various control problems [19–22].

References

[1] V. Hoang, M. Phung, T. Dinh, Q. Zhu, and Q. Ha, "Reconfigurable multi-uav formation using angle-encoded pso," in *Proc. of the 15th IEEE International Conference on Automation Science and Engineering (CASE'19), Vancouver, British Columbia, Canada*. IEEE, August 2019, pp. 1670–1675.

[2] X. Ai and J. Yu, "Flatness-based finite-time leader–follower formation control of multiple quadrotors with external disturbances," *Aerospace Science and Technology*, vol. 92, pp. 20–33, September 2019.

[3] R. Sharma and D. Ghose, "Collision avoidance between uav clusters using swarm intelligence techniques," *International Journal of Systems Science*, vol. 40, no. 5, pp. 521–538, May 2009.

[4] D. Sayfeddine, "Mechatronic control system for flying a quadrocopter and trajectory plan- ning using optical odometry," Ph.D. dissertation, Platov South-Russian State Polytechnic University, 2015.

[5] O. V. Baranov, "Quadrocopter control in emergency mode," *Vestnik of Saint Petersburg University. Applied Mathematics. Computer Science. Control Processes*, no. 2, pp. 69–79, June 2016.

[6] L. R. G. Carrillo, A. Dzul, R. Lozano, and C. Pégard, *Quad rotorcraft control: vision-based hovering and navigation*. Springer-Verlag London, 2013.

[7] A. S. Popkov, N. V. Smirnov, and O. V. Baranov, "Real-time quadrocopter optimal stabilization," in *Proc. of the 2015 International Conference S̈tability and Control Processesïn Memory of V.I. Zubov (SCP'15), Saint Petersburg, Russia*. IEEE, October 2015, pp. 123–125.

[8] I. Makkay, "Redundancy for uas - fail-safe engineering," in *Proc. of the 16th International Conference on Transport Means, Kaunas, Lithuania*. Kaunas University of Technology, October 2012, pp. 192–195.

[9] O. V. Baranov, N. V. Smirnov, and T. E. Smirnova, "On the choosing problem of PID controller parameters for a quadrocopter," in *Proc. of the 2017 Conference on Constructive Nonsmooth Analysis and Related Topics (dedicated to the memory of V.F. Demyanov) (CNSA'17), Saint Petersburg, Russia*. IEEE, May 2017, pp. 1–3.

[10] A. S. Popkov, O. V. Baranov, and N. V. Smirnov, "Application of adaptive method of linear programming for technical objects control," in *Proc. of the 2014 International Conference on Computer Technologies in Physical and Engineering Applications (ICCTPEA'14), Saint Petersburg, Russia*. IEEE, June 2014, pp. 141–142.

[11] O. V. Baranov, N. V. Smirnov, T. E. Smirnova, and Y. V. Zholobov, "Design of fail-safe quadrocopter configuration," in *Proc. of the 2019 International Symposium on Intelligent Distributed Computing (IDC'19), Petersburg, Russia*. Springer, Cham, October 2019, pp. 13–22.

[12] "eCalc - the most reliable electric Motor Calculator on the Web for RC Pilots," https://www.ecalc.ch/index.htm [Online; accessed on June 15, 2020].

[13] "Mission Planner Home — Mission Planner documentation," http://ardupilot.org/planner/ [Online; accessed on June 15, 2020].

[14] A. Hasan, V. Tofterup, and K. Jensen, "Model-based fail-safe module for autonomous multirotor uavs with parachute systems," in *Proc. of the 2019 International Conference on Unmanned Aircraft Systems (ICUAS'19), Atlanta, Georgia, USA*. IEEE, June 2019, pp. 406–412.

[15] R. Ermakov, I. Kuz'menko, E. Skripal, A. Seranova, D. Gutsevich, A. Abakumov, D. Livshits, K. Chekhovskaya, and A. L'Vov, "Aspects of designing a fail-safe flight and navigation system for unmanned aerial vehicles," in *Proc. of the 26th Saint Petersburg International Conference on Integrated Navigation Systems (ICINS'19), Saint Petersburg, Russia*. IEEE, May 2019, pp. 1–5.

[16] V. Sheval and N. Rozhnin, "Methods of increasing of onboard tracking system with optical device dynamic accuracy," in *Proc. of the 2019 International Scientific Siberian Transport Forum (TransSiberia'19), Novosibirsk, Russia*. Springer, Cham, January 2020, pp. 540–549.

[17] G. Michieletto, M. Ryll, and A. Franchi, "Fundamental actuation properties of multirotors: Force-moment decoupling and fail-safe robustness," *IEEE Transactions on Robotics*, vol. 34, no. 3, pp. 702–715, May 2018.

[18] N. V. Balashevich, R. Gabasov, and F. M. Kirillova, "Numerical methods of program and positional optimization of linear control systems," *Computational Mathematics and Mathematical Physics*, vol. 40, no. 6, pp. 838–859, January 2000.

[19] A. S. Popkov, N. V. Smirnov, and T. E. Smirnova, "On Modification of the Positional Optimization Method for a Class of Nonlinear Systems," in *Proc. of the 3rd International Conference on Applications in Information Technology (ICAIT'18), Aizu-Wakamatsu, Japan*. ACM, November 2018, pp. 46–51.

[20] A. S. Popkov, "Application of the adaptive method for optimal stabilization of a nonlinear object," in *Proc. of the 2016 International Conference Stability and Oscillations of Nonlinear Control Systems (Pyatnitskiy's Conference) (STAB'16), Moscow, Russia*. IEEE, June 2016, pp. 1–3.

[21] D. V. Girdyuk, N. V. Smirnov, and T. E. Smirnova, "Optimal Control of the Profit Tax Rate Based on the Nonlinear Dynamic Input-Output Model," in *Proc. of the 3rd International Conference on Applications in*

Information Technology (ICAIT'18), Aizu Wakamatsu, Japan. ACM, November 2018, pp. 80–84.

[22] M. N. Smirnov, M. A. Smirnova, T. E. Smirnova, and N. V. Smirnov, "Multi-purpose control laws in motion control systems," *Information (Japan)*, vol. 20, no. 4, pp. 2265–2272, January 2017.

Author Biography

Oleg V. Baranov is a P.G. in the Faculty of Applied Mathematics and Control Processes, Saint Petersburg State University (SPbSU), Russia. Graduated in 2018. He has several works about PID Control and research behavior of quadrocopter emergency control. Research interests: unmanned aerial vehicles (UAVs), electric power. Since 2013, he has been engaged in modeling various UAVs, teaching how to make own devices in modeling lab for students.

Nikolay V. Smirnov is a Professor in the Faculty of Applied Mathematics and Control Processes, Saint Petersburg State University (SPbSU), Russia. Currently, he is the Head of the Mathematical Modelling of Economical Systems Department at SPbSU (2016 – now). He received his doctorate in 2006 with a dissertation "Methods of Synthesis of Multiprogram Controls in Different Classes of Dynamic Systems". He specializes in mathematical control theory and system analysis. Dr. Smirnov works in the area of control processes modelling in different applications: control of technical objects, analysis of stability and stabilization of dynamic systems, constructing of controlled dynamic models of macroeconomic systems, development of applied methodology for control processes modelling in social-economic systems. Nikolay Smirnov is a winner of several grant programs of the Government of Russian Federation and the Russian Foundation for Basic Research (RFBR), and has also a government award from the Ministry of Education and Science.

Tatiana E. Smirnova is an Associate Professor in the Faculty of Applied Mathematics and Control Processes, Saint Petersburg State University (SPbSU), Russia. She obtained her PhD from the Saint Petersburg State University. Her main research interest is currently focused on mathematical control theory, algebraic computation, and mathematical theory of motion stability and stabilization of program motions. Tatiana Smirnova is a winner of several grant programs of the Government of Russian Federation and the Russian Foundation for Basic Research (RFBR).

Yefim V. Zholobov is a Student in the Faculty of Applied Mathematics and Control Processes, Saint Petersburg State University (SPbSU), Russia. Currently study at the Mathematical Modelling of Economical Systems Department at SPbSU. Research interests: Math Modelling, machine learning.