Problems of Emergency Situations

Scientific Applied Conference „Problems of Emergency Situations“ (PES 2022, Kharkiv, Ukraine)

Edited by
Prof. Dr. Volodymyr Andronov
Dr. Evgeniy Rybka
Prof. Dr. Yurii Otrosh
Dr. Alexey Vasilchenko
Dr. Nina Rashkevich
Dr. Andrii Kovalov

TRANS TECH PUBLICATIONS

Problems of Emergency Situations

Scientific Applied Conference
"Problems of Emergency Situations"
(PES 2022, Kharkiv, Ukraine)

Edited by
Prof. Dr. Volodymyr Andronov
Dr. Evgeniy Rybka
Prof. Dr. Yurii Otrosh
Dr. Alexey Vasilchenko
Dr. Nina Rashkevich
Dr. Andrii Kovalov

Problems of Emergency Situations

Scientific Applied Conference
"Problems of Emergency Situations"
(PES 2022, Kharkiv, Ukraine)

Selected peer-reviewed full text papers from the International Scientific Applied Conference "Problems of Emergency Situations", May 26-27, 2022, Kharkiv, Ukraine

Edited by

Prof. Dr. Volodymyr Andronov, Dr. Evgeniy Rybka, Prof. Dr. Yurii Otrosh, Dr. Alexey Vasilchenko, Dr. Nina Rashkevich and Dr. Andrii Kovalov

Scientific.Net

Trans Tech Publications Ltd
Kapellweg 8
CH-8806 Baech
Switzerland
https://www.scientific.net

Volume 114 of
Advances in Science and Technology
ISSN print 1662-8969
ISSN web 1662-0356

Full text available online at *https://www.scientific.net*

***Distributed** worldwide by*

Trans Tech Publications Ltd
Kapellweg 8
CH-8806 Baech
Switzerland

Phone: +41 (44) 922 10 22
e-mail: sales@scientific.net

Preface

The annual International Scientific Applied Conference "Problems of Emergency Situations" (PES, May 19, 2022, Kharkiv, Ukraine) is organized by the National University of Civil Defence of Ukraine (Ukraine, Kharkiv). As partners involved colleagues from the Odessa State Academy of Civil Engineering and Architecture (Ukraine, Odessa).

The conference was attended by scientists from 11 countries of the world – Ukraine, Israel, Poland, USA, Turkey, Germany, Sweden, Lithuania, Azerbaijanian Republic, Czech Republic and Slovakia.

The purpose of the conference was to discuss issues related to the problems and prospects of the introduction of the latest developments and technologies aimed at preventing emergencies, minimizing its consequences in field of civil defense, sharing experience and finding new facets of scientific cooperation, solving problems of recent emergencies and create a global threat to humanity.

The scientific program of the conference included plenary and sectional reports in the following areas:

1. Emergency prevention.
2. Scientific and practical aspects of monitoring and management in the field of civil protection.
3. Emergency response and elimination of their consequences.
4. Chemical technology and engineering, radiation and chemical protection.
5. Environmental safety and labor protection.

Readers will find here studies on using special software applications for modelling of technological process of manufacturing gear wheels and modelling a lathe with the design of standard layout schemes based on the upgraded spindle assembly.

The wide use of unmanned aerial vehicles and video communication systems for the identification of emergencies are the mainstream topics in modern systems of civil protection. Some research results on these issues are presented in this publication also.

The book will be interesting for many specialists whose activities are connected to engineering design in machinery and the creation and exploitation of systems for the identification of emergencies.

Table of Contents

Advances in Science and Technology
ISSN: 1662-0356, Vol. 114, pp 1-8
doi:10.4028/p-86xkq3

Submitted: 2022-03-13
Accepted: 2022-04-27
Online: 2022-07-29

Technological Process of Manufacturing a Gear Wheel Using the Abaqus Software Product Method

RUBAN Artem[1,a*], PASTERNAK Viktoriya[2,b], ZHYHLO Anna[3,c] and KONOVAL Volodymyr [4,d]

[1]National University of Civil Defence of Ukraine, 94 Chernishevska str., Kharkiv 61023, Ukraine

[2]Lutsk National Technical University, 75, Lvivska str., Lutsk, Ukraine, 43018

[3]Kharkiv National University of Municipal Economy named after O.N. Beketova, Kharkov, Marshal Bazhanov, 17, Kharkiv, Ukraine, 61002

[4]Cherkassy State Technological University, 460, Shevchenko boul., Cherkassy, Ukraine, 18006

[a]ruban_artem1979@ukr.net, [b]Shyberko@ukr.net, [c]Anna.Baranova@kname.edu.ua, [d]KonovalVolodymyr2019@gmail.com

Keywords: modelling, part, teeth, quality indicators, strength, transcendent system, modulus, oscillation, time point, profile, shear angle, transformation step.

Abstract. In this paper, we consider a detailed technological process for manufacturing parts, namely, a gear wheel. The proposed method with the intervention of modern 3D modelling makes it possible to improve the main indicators of quality and strength of parts. Based on the results obtained, a cycloid transcendental system of circular motion of a gear wheel with the specified basic parameters was modelled. Using multifunctional modules, we studied the vibrations of the gear wheel at different points in time. It was found that due to the fatigue and contact strength, it is possible to ensure uniform flexural strength of the gear teeth. And also, by adjusting the profile of the teeth of the part, we selected the desired strengthening coefficient. The presented dependence of the angles of inclination of the gear teeth on the transformation coefficient allows you to improve the main indicators of quality and strength by at least 2 %.

1 Introduction

Computer and information technologies of our time formulate the scientific and technological progress of mankind and create in general the information foundation for the development of science [1, 2, 3]. It should be noted that obtaining long-lasting indicators of quality [4, 5] and strength [6, 7] with their unique properties is possible with the help of new research technologies [8, 9, 10], which are based on improving accuracy, load capacity, as well as reducing the mass of parts [11, 12]. It should also be noted that the analysis of the main quality indicators of the studied parts will further improve and predict, first of all, these indicators [13, 14], as well as make it possible to improve the efficiency of the mechanism itself, reduce noise and vibration, as well as increase the durability of the part structure as a whole [15]. A special place in modern mechanical engineering technology is occupied by the technological process of manufacturing and processing gears [16] or gears [17], which is associated with high complexity of work and high labour intensity [18]. Because when manufacturing them, it is necessary to take into account a number of quality indicators, namely [19]: high and specific strength, corrosion resistance, a combination of high strength in one source material, as well as their chemical inertia, sound absorption, low thermal conductivity, etc [20, 21]. Thus, to study, analyse and generally justify the main indicators of quality and strength of parts of any type and various purposes with the latest methods of the Abaqus software product is an urgent task of modern mechanical engineering technology.

2 Main Part

The relevance of the use of modern and computer technologies in the study of a wide range of issues related to modelling is reflected in many publications on this topic [22]. It should be noted that these publication studies have worked out both the main issues of theoretical regularities of computer modelling [23, 24], and practical aspects with a more specific description of the technological process of manufacturing parts [25]. The main issues related to the use of 3D modelling [26, 27] in various branches of industrial activity are studied by many scientists, in particular [28, 29]. Research teams [30] have highlighted the main points of research that arise in the manufacture of structural parts [31]. The peculiarity of these works is that the range of computer modelling is limited by certain physical conditions of their existence [32, 33]. And also, the authors claim that the development of information technologies constantly puts forward new requirements for a modern design engineer of any industry [34, 35]. At the same time, indicators of the quality and strength of parts are not taken into account, which in the future allow predicting the durability of parts as a whole [36]. It should be noted that in many cases there are increased requirements both for modelling parts with design elements [37, 38, 39] and for creating design [40] and technological documentation [41], which is the main standard for the technological process of manufacturing parts in production conditions [42, 43]. Therefore, solving such a problem requires a more comprehensive and broader approach, which directly includes the use of new and modern-functional computer technologies. Namely: the main patterns of construction of parts during design, new ideas, methods and basic principles of the step-by-step technological process of manufacturing parts for any purpose, which means conducting fundamental and applied interdisciplinary research using the latest production methods and technologies.

The purpose of the work: to study, analyse and substantiate the main indicators of the quality and strength of gears using the methods of the modern Abaqus software product.

Materials. Modelling was performed in the Abaqus software package, which has the following main research models: Part, Property, Assembly, Step, Interaction, Load, Mesh, Job, Visualization, Sketch. For a detailed study of the technological process of manufacturing parts, and the gear wheel itself, a multifunctional visualization data module was used. The main indicators of quality and strength were based on a cylindrical coordinate system with a thickness of *h* and a radius of *R*. The profile of the teeth of the gear wheel was depicted in the form of a circular shape. That is, the basic Novikov theory, which is characteristic of one or two coupling lines, was fulfilled. It is also a cycloid transcendental system. In addition, this system is designed to transmit the main movement to the gear wheel or receive feces from it. In Fig. 1 shows modelling of a gear wheel using the Abaqus software product and its main parameters.

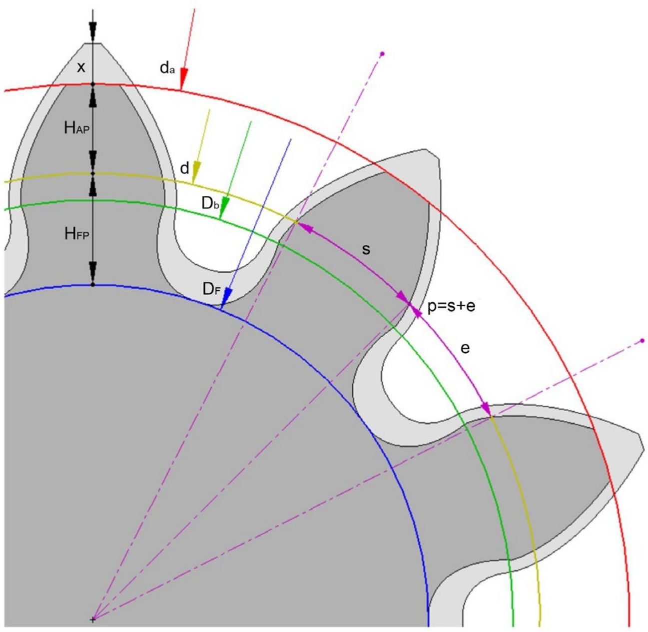


Fig. 1. Gear wheel modelling using a software product Abaqus and its main parameters

It should be noted that the main parameters that are responsible for the quality and strength of this design part are as follows:

x – the tool displacement error that occurs during the manufacture of the gear wheel and is equal to ± 0.2 mm;

H_{AP}, H_{FP} – the height of each (individual) gear tooth;

d_a – diameter of the common circles of the tops of the teeth of the part;

d – the main diameter of the dividing circle of the part;

D_b – diameter of the gear wheel involute (main circle);

D_F – diameter of gear depressions;

s – total number of teeth of the part;

e – distance between teeth;

$p = s+e$ – a function of tooth steps, namely: along the dividing circle.

It should also be noted that these quality and strength parameters are presented in the form of piezoelectric pads of the same thickness δ and radius $r_0 \leq R$. The outer and inner surfaces of this part are bordered by a passive layer, which is covered with infinitely thin continuous electrodes. The gear wheel is affected by an axisymmetric surface pressure, which is evenly distributed along the radius and is equal to: $P = P_0\cos(\omega t)$, which varies within a certain time t with a circular frequency ω, which is close to the natural oscillation frequency. In addition, the main functions of electrical potentials are performed, which are: $\psi\,(h / 2 + \delta) - \psi\,(- h / 2 - \delta) = R_e\,(2\,V_a^{iwt}\,)$. This function interacts with the frequency of mechanical loading, where: $V_a = V_a' + i\,V_a''$, and a small perturbation process occurs. Modeling the behavior of a gear wheel is generally based on the basic Kirchhoff-Lyav statements and hypotheses, and is mainly reduced to solving ordinary and differential equations.

Tests. With help of the additional multifunctional modules: Visualization, Assembly, Step-Interaction of the Abaqus software product, the number of gears was analysed at the moment of the hour, which was changed at the interval t = 450 °C – 850 °C. When modelling these details, they were asked to sing small details, the teeth of the teeth were sniffed at low speeds, the steel of the 40 grade was taken as the basis of the main material, so it was easy to get a sparkle in the middle (oil quenching was used) and the temperature was 550-650 °C at the same NV The door is 200-300, and the HRC becomes 50-60.

Figure 2 shows a model of a gear wheel at the moment of the hour t = 450 °C, and figure 3 shows a model of a gear wheel at the moment of the hour t = 500 °C.

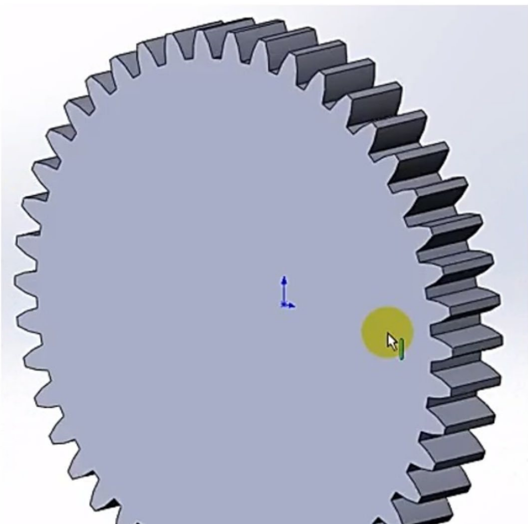


Fig. 2. Gear oscillation at a point in time t = 450 °C

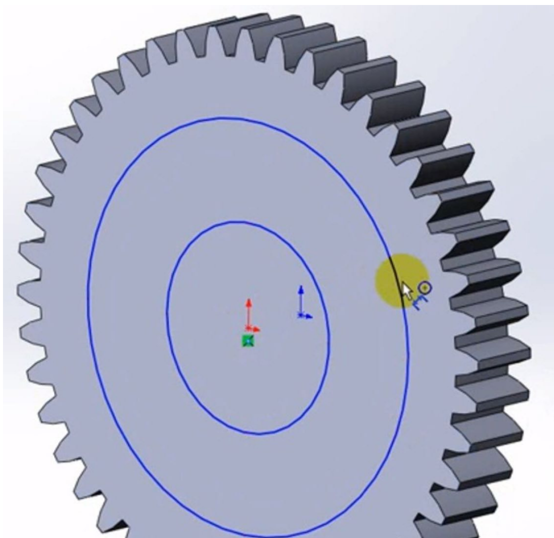


Fig. 3. Gear oscillation at a point in time t = 500 °C

It should be noted that the results obtained show a significant increase in the main quality parameters due to the fatigue and contact strength that occurred during gear modelling and which we were able to observe during modelling based on the Abaqus software product. And it is also important that when adjusting the profile of the teeth of the part itself, it was possible to choose the desired coefficient of strengthening due to the initial contour of the teeth, which provided uniform bending strength of the teeth of the gear wheel, or easily allowed a hole of any size and shape. It should also be noted that the results obtained are fully correlated with the recommendations of GOST 13755-68. Thus, it was decided to increase the oscillation of the gear wheel at time from t = 600 °C to t = 850 °C. From a number of studies, it follows that to a certain extent, the increase in the tooth thickness of this part occurs due to the adjustment of its profile, as well as the displacement of the original generatrix contour with a coefficient $x_i > 0$.

In Fig. 4 shows a simulation of a gear wheel at time t = 600 °C, and figure 5 shows a simulation of a gear wheel with asymmetric through holes at time t = 850 °C.

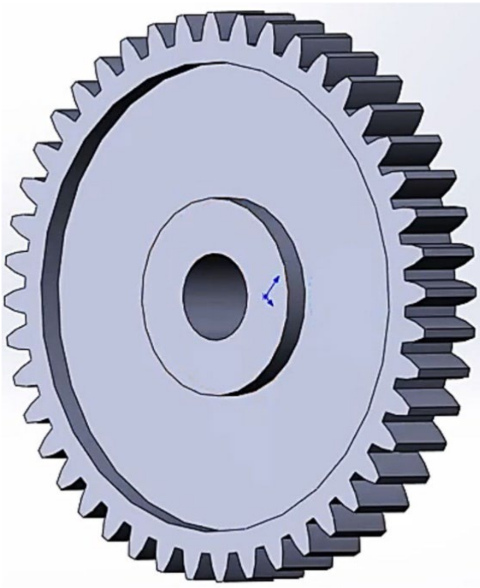


Fig. 4. Gear oscillation at a point in time t = 600 °C

Fig. 5. Gear oscillation at a point in time t = 850 °C

The conducted studies show that the angle of inclination of the gear teeth plays an important role in increasing the oscillation at a certain point in time. Also, each of the transformed cylindrical and spur wheels can be made in the form of a specific block, which consists of two identical wheels and with a given shear angle along the transformation step. Therefore, it can be argued that the gears must be modelled helical with a certain given angle of teeth, which allows you to provide the necessary end and axial overlap coefficient. The results obtained allow us to improve the main indicators of quality and strength by at least 2 %. Figure 6 shows the dependence of the angles of inclination of the gear teeth on the transformation coefficient.

The obtained dependence shows that the specified angles of inclination of the gear teeth increase due to an increase in the transformation coefficient of a certain tooth pitch. This additionally allows you to improve the main indicators of quality and strength, as well as predict additional parameters, namely: modulus, gear tooth height coefficient, part tooth profile angle, transformation coefficient, as well as permissible radial clearance coefficients.

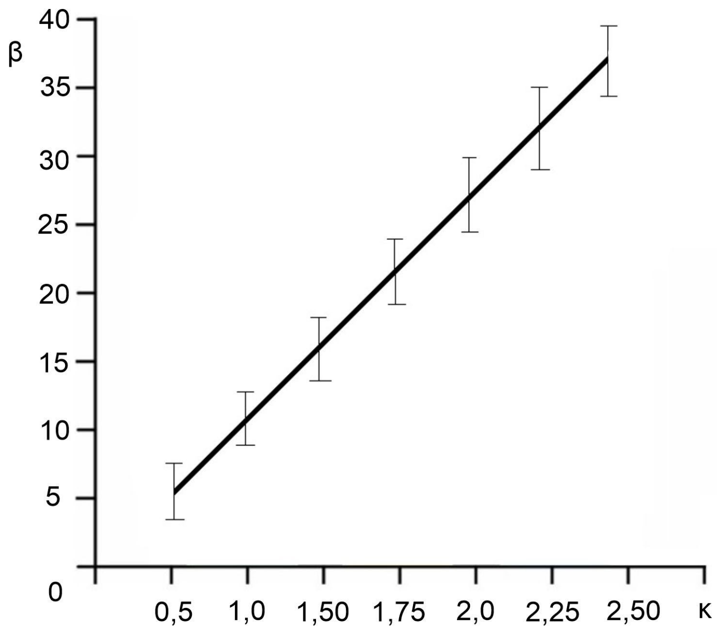


Fig. 6. Dependence of the angles of inclination of the gear teeth on the transformation coefficient, where: β – is the angle of inclination of the gear tooth, k – is the transformation coefficient of a certain pitch of the teeth of this part

3 Conclusion

From a number of studies conducted, it follows that:

1) the transformation of a certain pitch of the teeth of parts, namely the gear wheel, occurs with constant and basic parameters of quality and strength, namely: modulus, the height coefficient of the gear tooth, the angle of the profile of the teeth of the part, the transformation coefficient, as well as permissible radial clearance coefficients. The results obtained make it possible to model a gear wheel that has acceptable diametric dimensions and the same geometry of the tooth surfaces as untransformed gears. The main point in this case is modelling a certain tooth thickness, which allows you to significantly increase the bending strength of the gear teeth, or easily make a hole of any size and shape;

2) the problem of overlapping the teeth of the gear wheel is solved on the basis of the fact that the transformed gears must be modelled with helical teeth and with a certain angle of inclination of the teeth of the part, which directly depends on the transformation coefficient and increases due to its increase indicators;

3) the teeth of the gear wheel transformed in a certain step can also be modelled by copying, which directly allows you to improve the main indicators of quality and strength of parts by at least 2 %.

References

[1] F. Sgarbossa, M. Peron, Fr. Lolli, El. Balugani, Conventional or additive manufacturing for spare parts management: an extensive comparison for Poisson demand, International Journal of Production Economics 233 (2021) 1-16.

[2] V. Barannik, Y. Ryabukha, N. Barannik, D. Barannik, Indirect Steganographic Embedding Method Based on Modifications of the Basis of the Polyadic System. Proceedings – 15th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering, TCSET 2020. 9088673 (2020) 699–702.

[3] A. Kovalov, Yu. Otrosh, M. Surianinov, T. Kovalevska, Experimental and computer researches of ferroconcrete floor slabs at high-temperature influences, Materials Science Forum, 968 (2019) 361–367.

[4] I. Abbas, Ah. Abdulwahhab, A. Shabeeb, Influence of FECL3 on material removal rate and surface roughness in chemical machining process, Kufa Journal of Engineering 10 (2019) 44-55.

[5] Shostak I., Rahimi Y., Danova M., Feoktystova O., Melnyk O. Ensuring the security of the full logistics supply chain based on the вlockchain technology. CEUR Workshop Proceedings, 2393 (2019) 655–663.

[6] K. Amresh, Gr. Neelkant, M. Alakesh, S. Jasgurpreet, K. Raman, S. Sunpreet, P. Chander, Iu. Catalin, Investigating the influence of WEDM process parameters in machining of hybrid aluminum composites, Advanced Composites Letters, 29 (2020) 1-14.

[7] Sokolov D., Sobyna V., Vambol S., Vambol V. Substantiation of the choice of the cutter material and method of its hardening, working under the action of friction and cyclic loading. Archives of Materials Science and Engineering, 94 2 (2018) 49–54.

[8] J. Pereira Rodrigues, C. Francisco do Nascimento, S. Rogerio de Freitas Batista, L. Vilarinho, J. Meneses Barros, R. Gonçalves, Influence of the surface finish on corrosion resistance of stainless steels through machining and remelting on weld bead, Acta Scientiarum, Technology, 41 (2019) 1-10.

[9] S. Vambol, V. Vambol, O. Kondratenko, Y. Suchikova, O. Hurenko Assessment of improvement of ecological safety of power plants by arranging the system of pollutant neutralization. Eastern-European Journal of Enterprise Technologies, 3 10–87 (2017) 63–73.

[10] G. Khrypunov, S. Vambol, N. Deyneko, Y. Suchikova, Increasing the efficiency of film solar cells based on cadmium telluride, Eastern-European Journal of Enterprise Technologies, 6 5 (2016) 12–18.

[11] J. Varga, T. Tóth, P. Frankovský, L. Dulebová, E. Spišák, I. Zajaˇcko, J. Živˇcák, The influence of automated machining strategy on geometric deviations of machined surfaces, Applied Sciences, 11 (2021) 1-15.

[12] A. Kondratiev, V. Píštěk, L. Smovziuk, M. Shevtsova, A. Fomina, P. Kučera, Stress–strain behaviour of reparable composite panel with step–variable thickness, Polymers, 13 21 (2021) 3830.

[13] Ar. Sidhu, S. Singh, R. Kumar, D. Pimenov, Kh. Giasin, Prioritizing energy-intensive machining operations and gauging the influence of electric parameters: an industrial case study, Energies, 14 (2021) 1-39.

[14] A. Panchenko, A. Voloshina, O. Boltyansky, I. Milaeva, I. Grechka, S. Khovanskyy, M. Svynarenko, O. Glibko, M. Maksimova, N. Paranyak, Designing the flow-through parts of distribution systems for the PRG series planetary hydraulic motors, Eastern-European Journal of Enterprise Technologies, 3 1–93 (2018) 67–77.

[15] V. Pasternak, O. Zabolotnyi, N. Ilchuk, D. Cagáňová, Y. Hulchuk, Improvement of processes for obtaining titanium alloys for manufacturing parts with design elements, Lecture Notes in Mechanical Engineering, (2022) 323-333.

[16] S. Mehrafsun, H. Messaoudi, Dynamic process behavior in laser chemical micro machining of metals, Journal of Manufacturing and Materials Processing, 2 (2018) 1-18.

[17] Wan-Sik. Woo, Eun-Jung. Kim, Ho-In. Jeong, Choon-Man Lee, Laser-assisted machining of Ti-6Al-4V fabricated by DED additive manufacturing, International Journal of Precision Engineering and Manufacturing-Green Technology, 7 (2020) 559-572.

[18] J. Yuan, J. Boyd, D. Covelli, T. Arif, S. Fox-Rabinovich, S. Veldhuis, Influence of workpiece material on tool wear performance and tribofilm formation in machining hardened steel, Lubricants, 4 (2016) 1-10.

[19] H. Sulym, Ia. Pasternak, V. Pasternak, Boundary element modeling of pyroelectric solids with shell inclusions, Mechanics and Mechanical Engineering, 22 (2018) 727-737.

[20] L. Kondratenko, L. Mironova, On the influence of thermal processes on the dynamics of a drill during deep hole machining, MATEC Web of Conferences, 298 (2019) 1-7.

[21] Matyushenko I., Danova M., Feoktystova O., Melnyk R. Formation of teams of performers of projects at innovative enterprises within the framework of the Industry 4.0 concept. International Journal of Supply Chain Management, 8 4 (2019) 962–969.

[22] S. Hameed, H. González Rojas, J. Perat Benavides, A. Nápoles Alberro, A. Sánchez Egea, Influence of the regime of electropulsing-assisted machining on the plastic deformation of the layer being cut, Materials, 11 (2018) 1-10.

[23] B. Kucharska, J. Sobiecki, P. Czarniak, K. Szymanowski, K. Cymerman, D. Moszczy´nska, P. Panjan, Influence of different types of cemented carbide blades and coating thickness on structure and properties of TiN/AlTiN and TiAlN/a-C:N coatings deposited by PVD techniques for machining of wood-based materials, Materials, 14 (2021) 1-17.

[24] Singh Nain S., Sai R., Sihag P., Vambol S., Vambol V. Use of machine learning algorithm for the better prediction of SR peculiarities of WEDM of Nimonic-90 superalloy. Archives of Materials Science and Engineering, 95 1 (2019) 12–19.

[25] O. Zabolotnyi, V. Pasternak, I. Andrushchak, N. Ilchuk, K. Svirzhevskyi, Numerical simulation of the microstructure of structural-inhomogeneous materials, Lecture Notes in Mechanical Engineering, (2020) 562-571.

[26] An. Markopoulos, Em. Papazoglou, P. Karmiris-Obrata´nski, Experimental study on the influence of machining conditions on the quality of electrical discharge machined surfaces of aluminum alloy Al5052, Machines, 8 (2020) 1-13.

[27] Mygal V., Mygal G., Balabanova L. Visualization of signal structure showing element functioning in complex dynamic systems – Cognitive aspects. Journal of Nano- and Electronic Physics, 11 2 (2019) № 02013.

[28] V. Pasternak, L. Samchuk, N. Huliieva, I. Andrushchak, A. Ruban, Investigation of the properties of powder materials using computer modeling, Materials Science Forum, 1038 (2021) 33-39.

[29] Potopalska, K., Tyshkovets, O., Kalinovskyi, A., Vasyliev, S. An experimental study on elastic and strength properties of addictively-manufactured plastic materials (2021) Materials Science Forum, 1038 MSF, 162-167.

[30] Chen. Xuehui, Xu. Xin, Liu. Wei, Huang. Lei, Li. Hao, Wu. Chao, Mu. Weihao, Li. Xiang, Study on the influence of surface temperature field of aluminum alloy etched by laser water jet composite machining, Materials,13 (2020) 1-21.

[31] I. Ryshchenko, L. Lyashok, A. Vasilchenko, A. Ruban, L. Skatkov, Electrochemical synthesis of crystalline niobium oxide, Materials Science Forum, 1038 (2021) 51-60.

[32] R. Cep, L. Cepova, Cr. Borzan, J. Kasal, M. Sadilek, D. Sokova, M. Hatala, J. Petru, D. Stancekova, M. Pagac, J. Hajnys, O. Mizera, Influence of coolant pressure size on surface roughness when stainless steel machining, MATEC Web of Conferences, 299 (2019) 1-10.

[33] Yu. Otrosh, M. Surianinov, O. Holodnov, O. Starova, Experimental and computer researches of ferroconcrete beams at high-temperature influences, Materials Science Forum, 968 (2019) 355–360.

[34] B. Freire, M. Babcinschi, L. Ferreira, B. Senaris, F. Vidal, P. Neto, Direct energy deposition: a complete workflow for the additive manufacturing of complex shape parts, Procedia Manufacturing, 51 (2020) 671-677.

[35] Gaydamaka A., Kulik G., Frantsuzov V., Hrechka I., Khovanskyi S., Rogovyi A., Svynarenko M., Maksimova M., Paraniak N. Devising an engineering procedure for calculating the ductility of a roller bearing under a no-central radial load. Eastern-European Journal of Enterprise Technologies, 3 7–99 (2019) 6–10.

[36] O. Blyznyuk, A. Vasilchenko, A. Ruban, Y. Bezuhla, Improvement of fire resistance of polymeric materials at their filling with aluminosilicates, Materials Science Forum, 1006 (2020) 55-61.

[37] Yan. Li, Chen. Su, Jianjun. Zhu, Comprehensive review of wire arc additive manufacturing: hardware system, physical process, monitoring, property characterization, application and future prospects, Results in Engineering, 13 (2022) 1-17.

[38] O.Z. Dveirin, O.V. Andreev, A.V. Kondrat'ev, V.Ye. Haidachuk, Stressed state in the vicinity of a hole in mechanical joint of composite parts, International Applied Mechanics, 57 2 (2021) 234-247.

[39] Deyneko N., Semkiv O., Soshinsky O., Strelets V., Shevchenko R. Results of studying the cu/ito transparent back contacts for solar cells sno2:f/cds/cdte/cu/ito. Eastern-European Journal of Enterprise Technologies, 4 5–94 (2018) 29–34.

[40] N. Syreyshchikova, D. Pimenov, T. Mikolajczyk, L. Moldovan, Technological support of abrasive manufacturing of products on a flexible basis by evaluating performance indicators, Procedia Manufacturing, 46 (2020) 38-43.

[41] R. Wdowik, R. Ratnayake, M. Magdziak, Ar. Bełzo, Technological process planning focused on complex manufacturing processes of the digital era, Procedia Manufacturing 51 (2020) 1076-1081.

[42] A. Vasilchenko, O. Danilin, T. Lutsenko, A. Ruban, D. Nestorenko, Features of some polymer building materials behavior at heating, Materials Science Forum, 1006 (2020) 47-54.

[43] Hryhoriev S., Petryshchev A., Sinyaeva N., Yurchenko A., Sklyar O., Kvitka S., Borysov V., Vlasiuk V., Tsymbal B., Borysova S. Studying the physicalchemical properties of alloyed metallurgical waste as secondary resourcesaving raw materials. Eastern-European Journal of Enterprise Technologies, 4 12 (2018) 43–48.

Advances in Science and Technology
ISSN: 1662-0356, Vol. 114, pp 9-16
doi:10.4028/p-1298a7

Submitted: 2022-03-18
Accepted: 2022-04-28
Online: 2022-07-29

Current Trends in the Development of Automation Systems in Mechanical Engineering

Artem RUBAN[1,a] Viktoriya PASTERNAK[2,b*], Lyudmila SAMCHUK[2,c] , Alina HUBANOVA[1,d] and Oleg SUPRUN [3,e]

[1]National University of Civil Defence of Ukraine, 94 Chernishevska str., Kharkiv 61023, Ukraine

[2]Lutsk National Technical University, 75, Lvivska str., Lutsk, Ukraine, 43018

[3]Kharkiv National University of Municipal Economy named after O.N. Beketova, Kharkov, Marshal Bazhanov, 17, Kharkiv, Ukraine, 61002

[a]ruban_artem1979@ukr.net, [b]Shyberko@ukr.net, [c]samchuk@gmail.com, [d]alina22gubanova@gmail.com, [e]Oleh.Suprun@kname.edu.ua

Keywords: automation, machining, typical circuits, finite element method, precision, rigidity, speed, spindle assembly modernization.

Abstract. In this scientific study, the problem of automation of machine-building production is justified. A 3D model of the lathe is presented and its design is improved. Standard layout schemes based on the upgraded spindle assembly have been developed, which make it possible to increase the speed of this type of machine. The results obtained make it possible to achieve the desired cutting speed, which has significantly increased by 2-2,5 times. The constructed dependence of the deviation on the roundness of samples by the finite element method allows predicting the main indicators: feed rate, spindle speed, cutting depth, static imbalance, initial and final pressure. Also, the obtained analytical results allow us to establish the main regularities of forming the accuracy of this lathe.

1 Introduction

The development of new technologies and manufacturing processes is conditioned by the raise of requirements applied to materials and products made out of them [1]. Considerable attention has been recently paid to the problem of creation of learning systems, which are capable of improving their functioning in the course of time [2]. Analysis of the current level of development of automation of machine-building production shows that the most effective way to increase the competitiveness of machine tools, which leads to a reduction in the cost of design, production and operation of equipment, is the use of new intelligent technologies [3, 4]. The most important component of which is automated research systems [5, 6]. It should be noted that the practice of modern production and enterprises shows how quickly the requirements for the volume of batches of parts, the speed of their manufacture, cutting modes change with the advent of new materials, etc [7, 8, 9]. Thus, there is a need to develop machine systems based on computer modelling that could meet new requirements [10, 11]. It should also be noted that new machines should have quality indicators of rigidity and accuracy [12], while improved developments should be equipped with modern devices and systems [13] that could simplify the implementation of certain procedures, such as [14]: clamping the workpiece, positioning, tool replacement, as well as setting up equipment for batch production [15]. Based on previous research, the authors observed this that published rare research work on the use of machine learning in production [16]. Thus, current trends in the development of automation systems in mechanical engineering technology are an urgent task of our time, which require constant improvement and significantly new research results.

2 Main part

The study of current trends in the development of automation is covered in the works [17, 18]. The team of authors [19, 20] was engaged in research in the field of Industry 4.0. These studies are partly related to the desolate production technology [21, 22], that is, scientists are faced with the task of replacing manual labour of human labour with technical and automated research systems at all stages of development [23, 24]. Scientific results [25] reveal the basic principles of constructing ABC technological processes, the principles of creating automated production systems, and other subtleties of production automation [26, 27].

The peculiarity of these works is that the development trends of automated control systems are limited by thermal deformations of machine tools, which affect the accuracy of processing, which leads to a 30-50% increase in their cost [28, 29]. Thus, there is a need to create and improve such competitive metal-cutting machines that would fully satisfy the design and production conditions of any production or enterprise [30, 31]. It should be noted that the priority direction of improving the competitiveness of machines is to improve their quality due to the developed standard layout schemes of the spindle assembly, as well as accuracy and strength indicators, at least ± 1,5 %, which fully meets the requirements of GOST and technical conditions of production operation. Research teams [32, 33] describe a number of problems that focus mainly on the stiffness indicators of machine tools of any type [34]. At the same time, the permissible limits of the main parameters put forward by the standards for the operation of lathes are not taken into account, as well as external conditions that may affect the operation of the lathe are not taken into account. Taking into account a number of problems that still need to be improved and investigated, as well as an analysis of the current level of development of automation of machine-building production show that the most effective way to increase the competitiveness of metal-cutting machines is to reduce their design cost based on modernization, taking into account all the necessary conditions for the production and operation of equipment [35]. Thus, solving these problems requires a more comprehensive approach, including a set of new intelligent technologies, the most important component of which is automated control systems, which is an urgent task of our time.

The purpose of this paper is to investigate the process of modelling a lathe, as well as to develop standard layout schemes based on the upgraded spindle assembly. Construct the dependence of the deviation on the roundness of the samples using the finite element method.

Materials. Due to the increase in productivity and efficiency of mechanical processing processes, the issue of modelling forming units of metal-cutting machines in modern mathematical and computer modelling systems is becoming increasingly important. It is important to note that the analysis of the balance of pliability and vibration patterns of the main components of lathes shows that the main components of turning automation include: the spindle, the workpiece and the caliper group, which determines the functioning of the machine as a whole. The stiffness and vibration resistance characteristics of the spindle on elastic supports depend on the size of the cantilever part of both the spindle itself and the length of the workpiece.

Obviously, a lathe is a type of machine that is designed to perform a variety of turning operations, as well as for cutting metric, inch, modular, pitch and end threads. The main components of the lathe include: bed, headstock, tailstock, caliper, guitar, feed box, gearbox and apron.

The basis for automation of lathes is the bed, which serves for the installation of all major assembly units. The caliper carriage and tailstock move along the bed guides.

The headstock is usually rigidly installed on the left side of the frame. It should be noted that it also contains a gearbox. A chuck is attached to the spindle in which the workpieces are clamped.

The tailstock supports the free end of long workpieces, or is used for drilling holes. It consists of three parts: the body, the panel and the plate. A centre or axial tool can be installed in the conical pinole hole. If necessary, the tailstock body is shifted in the transverse direction to process conical surfaces.

The caliper is designed for fixing the cutters in the tool holder, and is also responsible for moving them in the longitudinal and transverse directions.

The guitar is used to transmit rotation from the gearbox to the feed box.

The feed box transmits rotation to the lead screw or lead shaft. Its design allows you to adjust the machine to the required feed or thread cutting step.

The apron contains gears that serve to transmit torque to move the caliper in a parallel direction or perpendicular to the spindle axis. In this case, the feed is carried out by means of a flywheel, which is connected through gears to a gear rack attached to the machine bed.

In Fig. 1 a general view of the lathe is represented.

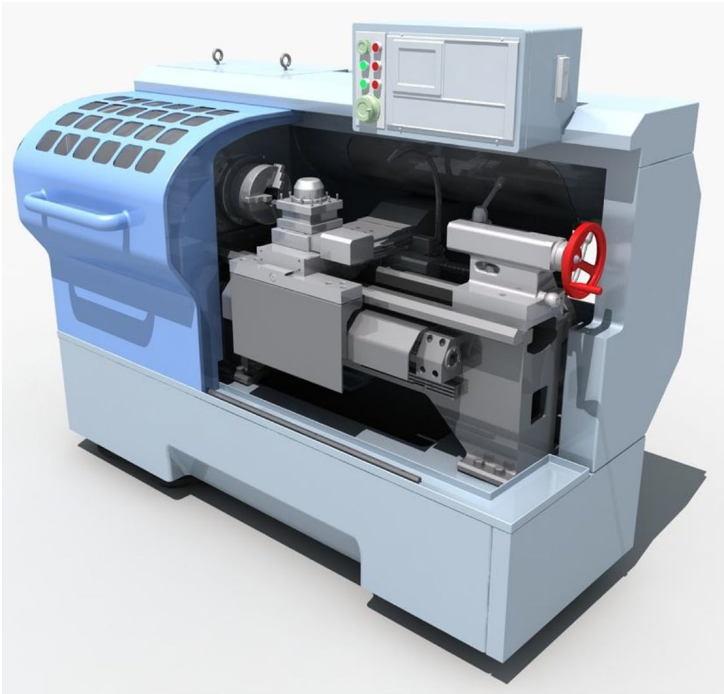


Figure 1. 3D lathe model

The principle of operation of the lathe proposed by us is as follows: mechanical feed from the running shaft is carried out through a worm located on a sliding key. The worm rotates the wheel and through the cam clutch and gears, the movement is transmitted to the pair to the rack with the gear. When processing threads, the torque is transmitted through the lead screw to the master nut, in all other cases it is open. It should be noted that when processing complex curved surfaces on the machine, a hydraulic copying caliper can be used, which automates the processing process. In turn, when processing holes with a special lock, the tailstock can be connected to the caliper and receive mechanical feed. The apron is presented in the form of a spring coupling, which allows you to process parts with a stop, and also automates the processing process.

Tests. The optimization parameter is the development of the main standard layout schemes for spindle units, as well as some deviation from the roundness of the surfaces of samples that were made of grade 45 steel on a lathe (Figure 1) with an upgraded spindle assembly (Figure 4 and Figure 5). It should be noted that an important factor that affects the optimization process in this case is the cutting modes, which mainly include the feed functions – S, spindle speed – n and cutting depth – t. A static imbalance – D_{CT} was also recorded, which fluctuated within acceptable limits, and the initial pressure – P was set, which actually did not change after the experiment.

Fig. Figure 2 shows the developed standard layout scheme of the spindle assembly.

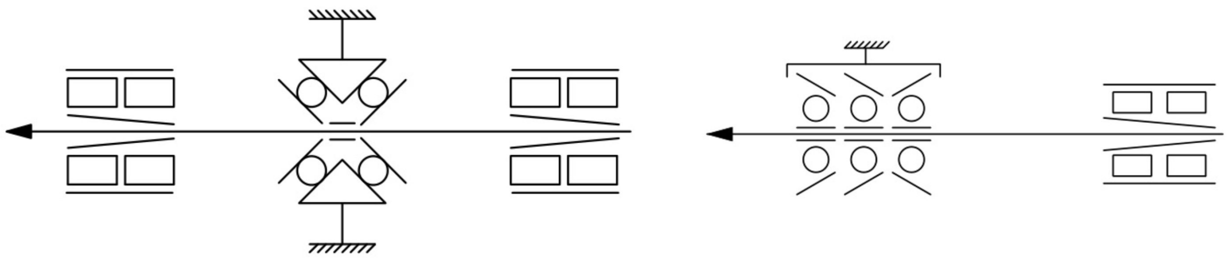


Figure 2. Typical layout of a spindle assembly

It should be noted that the results obtained allow us to obtain high rigidity and speed. At the same time, the maximum frequency is 4500 rpm, and the stiffness is reached by 10/10 Kr. It should also be noted that a typical layout scheme for the spindle assembly has been developed in Fig. 2 allows you to predict the speed of the machine, which is shown in Fig. 3.

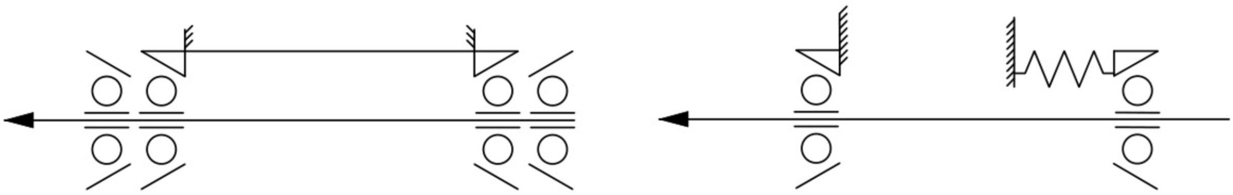


Figure. 3. Typical lathe speed scheme

An important point is that by increasing the speed, we were able to achieve the desired cutting speed, which increased by 2-2,5 times. These advantages are mainly achieved with the help of an upgraded spindle assembly. And also, a small deviation that occurs on the treated surface of the sample, which was made of steel grade 45. Figure 4 shows an upgraded spindle assembly using the SolidWorks software product. And Figure 5 presents a spindle assembly that was manufactured under production conditions in compliance with all basic GOST requirements.

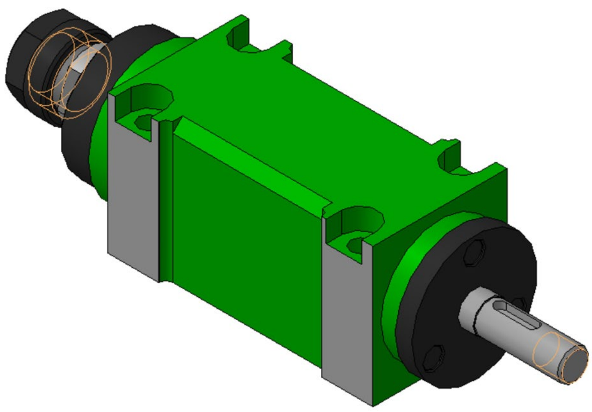


Figure 4. Upgraded spindle assembly using the SolidWorks software product

Figure 5. A spindle assembly that is manufactured under production conditions

It should be noted that the diameter of the upgraded spindle assembly according to the strength criterion is d = 30 mm. During the design process, the main fastening was carried out in the front and rear supports, on which certain permissible loads were set. As part of the study, the obtained safety margin coefficient makes it possible to increase the efficiency of procedures for studying the main technical and economic properties of forming samples (products). And also, to justify the dependence of a small deviation from the roundness of products, which occurs on the treated surface.

In Figure 6 the dependence of the deviation on the roundness of samples that were made using a lathe is presented.

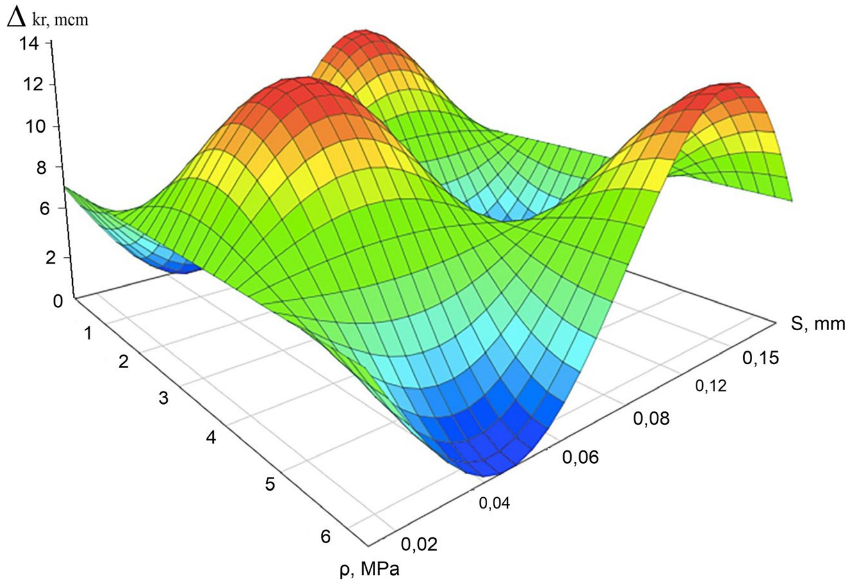


Fig. 6. Dependence of the deviation on the roundness of samples, which is shown using the finite element method

Analysing the presented dependence, which is shown in Figure 6, it can be concluded that with an increase in the gradual cutting depth, there is a slight deviation from the roundness of the treated surfaces of samples that were made of grade 45 steel. This is due to an increase in the cutting force, on which the elastic deformations of the elements and the vibration activity of the upgraded spindle assembly depend. It should also be noted that the resulting deviations lie within the permissible error and are equal to ± 1,5 %, which fully corresponds to the technical conditions of production.

3 Conclusion

Thus, we can conclude that with the help of the process of modelling a lathe, it is possible to improve its design. It should be noted that the level of natural vibrations of individual nodes and the control system as a whole is low. These deviations lie within the permissible limits of ± 1,5 %, these are normal indicators for machines of normal accuracy class. Based on the upgraded spindle unit, we developed a typical lathe speed scheme, and also by increasing the speed, we were able to achieve the desired cutting speed, which increased by 2-2,5 times. Typical layout schemes generally allowed us to record a small deviation that occurs on the treated surface of samples. The deviation occurs due to an increase in the cutting force.

It should also be noted that the constructed dependence of the deviation on the roundness of samples by the finite element method allows us to predict the following main parameters:

1) feed – S;
2) spindle speed – n;
3) cutting depth – t;
4) static imbalance – D_{CT};
5) initial and final pressure – P.

An important point is that the analytical results allow us to establish the main regularities of the formation of the accuracy of this lathe, and also the statistical imbalance of the rotating elements of the lathe can be controlled (if any) by the accuracy indicator.

References

[1] S. Vambol, V. Vambol, V. Sobyna, V. Koloskov, L. Poberezhna, Investigation of the energy efficiency of waste utilization technology, with considering the use of low-temperature separation of the resulting gas mixtures, Energetika, 64 4 (2018) 186–195.

[2] V. Andronov, B. Pospelov, E. Rybka, S. Skliarov, Examining the learning fire detectors under real conditions of application, Eastern-European Journal of Enterprise Technologies, 3 9 87 (2017) 53–59.

[3] B. Denkena, Eb. Abele, Ch. Brecher, M. Dittrich, S. Kara, M. Mori, Energy efficient machine tools, CIRP Annals – Manufacturing Technology 69 (2020) 646-667.

[4] A. Kondratiev, V. Píštěk, S. Purhina, M. Shevtsova, A. Fomina, P. Kučera, Self-heating mold for the composite manufacturing. Polymers, 13 18 (2021) 3074.

[5] M. Brillinger, M. Wuwer, M. Hadi, Fr. Haas, Energy prediction for CNC machining with machine learning, CIRP Journal of Manufacturing Science and Technology, 35 (2021) 715-723.

[6] S. Vambol, V. Vambol, O. Kondratenko, Y. Suchikova, O. Hurenko Assessment of improvement of ecological safety of power plants by arranging the system of pollutant neutralization. Eastern-European Journal of Enterprise Technologies, 3 10–87 (2017) 63–73.

[7] Hongping. Yang, Rongzhen. Zhao, Weiqian. Li, Cheng. Yang, Li. Zhen, Static and dynamic characteristics modeling for CK61125 CNC lathe bed basing on FEM, Procedia Engineering 174 (2017) 489-496.

[8] A. Kondratiev, V. Píštěk, L. Smovziuk, M. Shevtsova, A. Fomina, P. Kučera, Stress–strain behaviour of reparable composite panel with step–variable thickness, Polymers, 13 21 (2021) 3830.

[9] Sokolov D., Sobyna V., Vambol S., Vambol V. Substantiation of the choice of the cutter material and method of its hardening, working under the action of friction and cyclic loading. Archives of Materials Science and Engineering, 94 2. (2018) 49–54.

[10] As. Misra1, A. Sharma, Gh. Singh, As. Kumar, V. Rastogi, Design and development ofa low-cost CNC alternative SCARA robotic arm, Procedia Computer Science, 171 (2020) 2459-2468.

[11] A. Kovalov, Yu. Otrosh, M. Surianinov, T. Kovalevska, Experimental and computer researches of ferroconcrete floor slabs at high-temperature influences, Materials Science Forum, 968 (2019) 361–367.

[12] Ruisheng. Hou, Zongzhuo. Yan, Hongyang. Du, Tong. Chen, Tao. Tao, Xuesong. Mei, The application of multi-objective genetic algorithm in the modeling of thermal error of NC lathe, Procedia CIRP 67 (2018) 332-337.

[13] H. Zhang, R. Kuschmierz, J. Czarske, Miniaturized interferometric 3-D sensor for shape measurement inside of cutting lathes, Procedia CIRP 77 (2018) 46-49.

[14] Th. Gittler, F. Stoop, D. Kryscio, L. Weiss, K. Wegener, Condition monitoring system for machine tool auxiliaries, Procedia CIRP 88 (2020) 358-363.

[15] J. Wang, Q. Bi, J. Yu, Yu. Zhang, On-machine ultrasonic thickness measurement and compensation of thin-walled parts machining on a CNC lathe, Procedia CIRP 101 (2021) 246-249.

[16] Singh Nain S., Sai R., Sihag P., Vambol S., Vambol V. Use of machine learning algorithm for the better prediction of SR peculiarities of WEDM of Nimonic-90 superalloy. Archives of Materials Science and Engineering, 95 1 (2019) 12–19.

[17] V. Pasternak, O. Zabolotnyi, N. Ilchuk, D. Cagáňová, Y. Hulchuk, Improvement of processes for obtaining titanium alloys for manufacturing parts with design elements, Lecture Notes in Mechanical Engineering (2022) 323-333.

[18] T. Schmitz, Modal interactions for spindle, holders, and tools, Procedia Manufacturing, 48 (2020) 457-465.

[19] O. Zabolotnyi, V. Pasternak, N. Ilchuk, D. Cagáňová, Y. Hulchuk, Study of the porosity based on structurally inhomogeneous materials Al-Ti, Lecture Notes in Mechanical Engineering (2021) 349-359.

[20] Gaydamaka A., Kulik G., Frantsuzov V., Hrechka I., Khovanskyi S., Rogovyi A., Svynarenko M., Maksimova M., Paraniak N. Devising an engineering procedure for calculating the ductility of a roller bearing under a no-central radial load. Eastern-European Journal of Enterprise Technologies, 3 7–99 (2019) 6–10.

[21] Bora. Erena, Burak. Sencera, Mechanistic cutting force model and specific cutting energy prediction for modulation assisted machining, Procedia Manufacturing, 48 (2020) 474-484.

[22] V. Pasternak, L. Samchuk, N. Huliieva, I. Andrushchak, A. Ruban, Investigation of the properties of powder materials using computer modeling, Materials Science Forum, 1038 (2021) 33-39.

[23] Cl. Cooper, P. Wang, J. Zhang, R. Gao, Tr. Roney, Ih. Ragai, D. Shaffer, Convolutional neural network-based tool condition monitoring in vertical milling operations using acoustic signals, Procedia Manufacturing, 49 (2020) 105-111.

[24] I. Pasternak, V. Pasternak, R. Pasternak, H. Sulym, Stroh formalism in evaluation of 3D Green's function in thermomagnetoelectroelastic anisotropic medium, Mechanics Research Communications, 84 (2017) 20-26.

[25] R. Wdowik, R. Chandima Ratnayake, M. Żółkoś, M. Magdziak, G. Valiño, B. Álvarez, J. Misiura, Digitization methods of grinding pins for technological process planning, Procedia Manufacturing, 51 (2020) 1054-1061.

[26] R. Nikolić, M. Lučić, B. Nedić, M. Radovanović, Calculation of temperature fields during lathe machining with thermoelectrical cooling by using the finite element method, Thermal Science, 23 (2019) 1889-1899.

[27] Kamran. Shah, Hassan. Khurshid, Izhar. Ul Haq, Nauman. Khurram, Zeeshan. Ali, Conversion of a conventional lathe machine into a friction welding machine and performing some experimental tests for its operational feasibility, Mehran University Research Journal of Engineering and Technology, 40 (2021) 545-555.

[28] O. Blyznyuk, A. Vasilchenko, A. Ruban, Y. Bezuhla, Improvement of fire resistance of polymeric materials at their filling with aluminosilicates, Materials Science Forum, 1006 (2020) 55-61.

[29] Chih-Jer. Lin, Xiao-Yi. Su, Chi-Hsien. Hu, Bo-Lin. Jian, Li-Wei. Wu, Her-Terng. Yau, A linear regression thermal displacement lathe spindle model, Energies, 13 (2020) 1-14.

[30] P. Wang, Y. Wang, H. Yu, N. Cheng, H. Hao, Zh. Yan. Development of a new multi-purpose wrench based on a lathe, MATEC Web of Conferences, 353 (2021) 1-4.

[31] Az. Aliev, Ensuring the quality of the machined holes during the hole truing and reaming on lathe machines, MATEC Web of Conferences, 224 (2018) 1-5.

[32] Kaglyak, B. Romanov, K. Romanova, A. Ruban, V. Shvedun, Repeatability of sheet material formation results and interchangeability of processing modes at multi-pass laser formation, Materials Science Forum, 1038 (2021) 15-24.

[33] Is. Fernández-Osete, A. Estevez-Urra, Er. Velázquez-Corral, D. Valentin, J. Llumà, R. Jerez-Mesa, J. Travieso-Rodriguez, Ultrasonic vibration-assisted ball burnishing tool for a lathe characterized by acoustic emission and vibratory measurements, Materials, 14 (2021) 1-17.

[34] H. Jin, Av. Titus, Yu. Liu, Y. Wang, Zh. Han, Fault diagnosis of rotary parts of a heavy-duty horizontal lathe based on wavelet packet transform and support vector machine, Sensors, 19 (2019) 1-18.

[35] I. Ryshchenko, L. Lyashok, A. Vasilchenko, A. Ruban, L. Skatkov, Electrochemical synthesis of crystalline niobium oxide, Materials Science Forum, 1038 (2021) 51-60.

Advances in Science and Technology
ISSN: 1662-0356, Vol. 114, pp 17-25
doi:10.4028/p-5yhq80

Submitted: 2022-04-18
Accepted: 2022-04-24
Online: 2022-07-29

Issues of Resistance to Progressive Failure of Load-bearing Systems in LIRA-SAPR Software

BARABASH Maria[1,2,a]

[1]LIRA SAPR Ltd, Kiyanivski prov, 7A, Kyiv, Ukraine, 04053

[2]National Aviation University, prosp. Lubomira Guzara, 1, Kyiv, Ukraine, 03058

[a]bmari.lira@gmail.com

Keywords: progressive failure, load-bearing structures, nonlinear analysis, stability, quasi-static analysis, risks, explosive effects, dynamic factor.

Abstract. The article is devoted to the description of analytical and structural methods used in the design to avoid progressive collapse of buildings and structures in the case of extreme influences. Three directions are described to avoid the process of development of local to global destruction. The concept realized in the LIRA-SAPR software, which is aimed at automating analysis for progressive collapse in quasi-static and dynamic formulations, including linear and nonlinear analysis taking into account the dynamic factor, is also substantiated. The purpose of the analysis is to design structures for various purposes, which in addition to accident-free performance of functions during the specified period of operation, in case of an accident due to natural and man-made phenomena (defects in production technology, explosions, impacts), as well as other causes not provided for by the conditions of normal operation, would cause minimal damage to people and the environment.

Introduction

The concept of progressive failure (collapse) under conditions of military operations acquires a new relevance. Regardless of the source of occurrence and the nature of loading, progressive failure is qualified as a process of deformation development from local to global. In the current realities, it becomes necessary to consider in the analysis and design of every possibility of preventing progressive failure, especially in the design of multi-story building frameworks. For structures of another type, the so-called large-span structures: bridges, pavement systems, functioning on a flat and spatial scheme, the situation here is more uncertain, and it requires research aimed at studying the ways of preventing the turning a local failure into a global one.

Providing resistance to progressive failure is necessary for all buildings and structures. This means that these buildings must have structural measures in place to guarantee resistance to progressive failure.

It seems that the sources of progressive failure should be sought not in complex structural systems, but in the structure of the solid body itself. Fracture mechanics in the quest for detecting fracture zones and further development of cracks solves the same problem: Will the crack remain local or develop and lead to a complete failure of the body? For structurally anisotropic systems, the continuous crack propagation process becomes a stepwise developing one. Then it is possible to fix and prevent further "transitions" from local to global failure of the structure.

Problem statement

To solve this problem, it is necessary to analyze each load-bearing system, and to identify "weak points" and ways to prevent progressive failure. The current building regulations (reference to the Eurocode, DBN) [1] require that building structures and foundations must be designed so that they are sufficiently reliable during construction and maintenance, taking into account, if necessary, special effects (e.g. earthquakes, floods, fires, explosions).

Terrorist activity was a major trigger for the problem. Although even before it there was enough catastrophic destruction of buildings and structures. Today there are several regulations in the world governing the solution of the problem. Their difference from others is their constant development because the results of observations, research and recommendations for new construction accumulate quickly and are very popular. Among these standards are national standards of the USA, Canada, Great Britain, international standards: Eurocode 2 [1, 5], etc.

To ensure the prevention of local damage and turn it into a global one, there are three possible directions

– reducing the level of "risk",
– increase the degree of static indeterminacy of the system,
– design "responses" to possible damage.

1. Reducing the level of risk. There are at least two ways to solve the issue by reducing the level of "risk” like many other documents of previous years, solves this issue by introducing a coefficient of reliability on liability. For the first time, the coefficient of reliability according to the class of capital construction appeared in the design standards for hydraulic structures: γn =1.25 for constructions of the 1st class of reliability. It is obvious that such a directive assignment of the coefficient γn leads to significant additional costs, but at the same time significantly increases the safety in case of failures from known in magnitude, direction and nature of the impacts. In this case, the unsolvable problem is the damage due to unknown in the direction of the impacts and impacts after changing the design scheme [2].

Direct calculation of "risk" and its planned reduction, stipulated in the contract documents, is possible.

Let's illustrate the analysis method by an example of calculating the risk of bar failure from compression, which occurs in a terrorist attack (Fig. 1).

Let's denote by S the external force at which the bar should fail, and by R the force determined by fracturing the samples.

The bar will collapse if R < S или R - S < 0. The risk is equal to: m = R - S.

Mathematical expectation of risk:

$$\hat{m} = \hat{R} - \hat{S}; \sigma_{\mu} = \sqrt{\sigma_R^2 + \sigma_S^2} = \sigma_S \sqrt{1 + \sigma_R^2 / \sigma_S^2} = \sigma_S \alpha ...$$
$$\alpha = \sqrt{1 + \sigma_R^2 / \sigma_S^2}. \tag{1}$$

The probability P(x) when the variable x changes to u=(x-ξ)/σ:

$$\Phi(u) = (1/\sqrt{2\pi\sigma}) \int_{-\infty}^{u} e^{-u^2/2} du \tag{2}$$

and the risk is equal to

$$risk = P\{(R - S) > 0\} = 1 - P(m > 0) = \Phi(\frac{0 - m}{\sigma_m}) = \Phi(-\frac{m}{\sigma_m}).$$

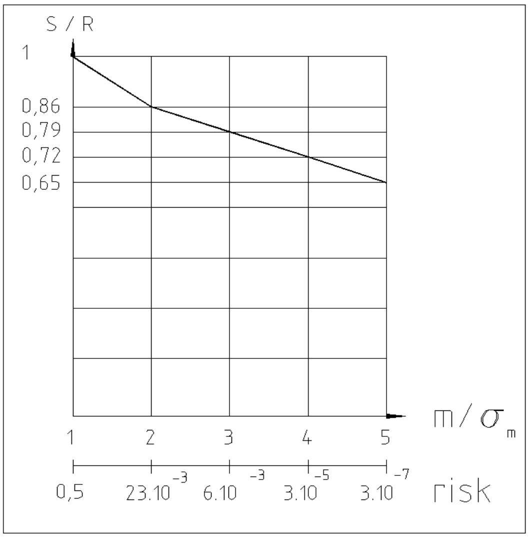


Fig. 1. Reducing risk by reinforcing the compressed bar

The graph in Figure 1 shows that reducing the load-to-resistance ratio from 1 to 0.65 reduces the risk from 0.5 to 3.10^{-7}.

It should be noted that reducing the degree of risk successfully solves only a necessary part of the problem – increasing the reliability of the framework in a way that is designed to resist operational stresses. However, the changes that have occurred in the frame: the formation of new hinges, the disappearance of some load-bearing elements, etc., have no effect on the level of risk while increasing the coefficient of reliability by designation. Therefore, let us emphasize that the solution turns out to be necessary, but not sufficient.

Risk reduction can also be achieved in a more effective way. To do this, it is necessary to pre-rank the structure itself and its constituent elements, specifying in each case the risk by the degree of consequences from each type of failure.

The goal is to reduce the risk of structural failure with little or no increase in costs. This solution lies in the field of designers, planners, builders, and operators.

The consequences of failure of connections between structural elements are not very different from the consequences arising from the failure of the elements. However, in reality, the difference is quite significant. Thus, the destruction of a single panel of flooring, if it does not lead to a domino effect, is dangerous only for the inhabitants of 1–2 rooms. The collapse of the girder threatens disaster for the occupants of one or more apartments. The failure of an upper floor column would be dangerous to the inhabitants of that floor and possibly the next floor after it, and the failure of the same column on the first floor or in the basement would cause much more severe consequences.

Modern design is based on the principle of equal reliability of all structural elements of the building. Obviously, this approach is unacceptable in the tasks of life support. It is also clear that a deterministic approach to such problems is also unacceptable. Only a probabilistic approach is possible, in which the probability of failure of each element is differentiated and assigned depending on the expected consequences.

To quantify the reliability of structural elements and the structure as a whole, it is advisable to rank the forms of failure and the consequences of failure [3, 4].

The lower limit should be flat shear, the upper limit – rolling over. Defects corresponding to the 2nd group of limiting states are not included in Table 1.

Such a ranking, for example, can be given in the form shown in Table 1.

Table 1.

Structure and type of failure	Point
Loss of stability (shear)	*
Failure of the floor slab of the ground floor	**
Failure of the roof slab of the upper floor	***
Failure of the floor beam of the lower floor	****
Failure of the upper floor beam	*** **
Failure of the top floor girder	*** ***
Failure of the ground floor column	*** *** **
Failure of the upper floor column	*** *** *
Failure of the wall panel of the ground floor	***
Failure of the wall panel of the upper floor	*** ***
Loss of stability on rollover	*** *** *** *** *** ***

This method exists today only in the form of a suggestion. It contradicts the principle of equivalence accepted in the norms. But it is this method that allows a more rational design of load-bearing structures. For unique structures, it can be technically and economically justified. A differentiated approach to the regulation of the acceptable level of risk allows to solve the problem of resistance to progressive failure more economically.

What can happen to a structure under extreme impact?

1. The building may lose stability against shear. In this case, the integrity of communications will be disrupted: there is a threat of basement flooding due to burst water pipes, heating and sewage systems; there will be blackouts or short circuits in electricity networks, elevators will stop; there is a threat of fire - panic may arise among the residents.
2. The building may lose stability against tipping. Even if there is no mutual displacement of structural elements or their destruction in the process of tipping, the probability of absence of human casualties is small. Basically, tipping in its pure form is only possible in monolithic reinforced concrete buildings. In prefabricated panel or frame-type buildings, including metal frame buildings, tipping usually leads to complete disruption of the connections between structural elements.
3. In a building there can be a breakdown of connections between structural elements: the floor panels are coming off the supports on the walls and beams, the joints of the columns are breaking off, the wall panels are detaching from the frame, and the connections between the panels themselves are breaking off.
4. Failure of structural elements: floor panels, frame girders, beams, frame struts, columns, and walls.
5. Excessive opening of cracks in the structural elements and enclosing structures.
6. Supernormal deflections of structural elements or mutual angles of rotation between them.

Let's try to analyze the severity of the consequences for each of the forms of violation of the design position, strength and deformative properties of the structure and its structural elements. Obviously, excessive crack opening or excessive deflections are not life-threatening for the residents of the apartment building. There is also no immediate threat to the life and health of the residents. There may be unfavorable consequences due to the occurrence of secondary causes.

As noted above, a tipping over can lead to the most severe consequences. We should add that in this case not only the residents of the house are at risk, but also everyone who is within a circle whose radius is equal to the height of the building.

2. Increasing the "extra" unknowns in the framework. Of course, this way – excessive static indeterminacy and frequently placed columns – is not a gift for architects. But in some cases it is a solution to the safety problem. This way can be very effective in the design of large-span lattice systems with lattice structures. By creating multilattice trusses and arches, by using combined systems like Langer trusses, Concider arches, hanging and cable-stayed systems with stiffening beams, the designer can and must create ways to back up the load capacity so that failure would not be sudden and catastrophic.

3. Analysis and design "responses" to possible damage. The third direction involves the design of systems capable of resisting the operational and emergency effects of changes in the design and structural scheme after local damage.

The advantage of one or another direction in the first place is assessed by economic indicators: it is the ratio of the cost of strengthening structures and losses caused by the accident.

It is believed that the third direction is the most economically justified and targeted.

The necessity and sufficiency of structural measures preventing progressive collapse must be confirmed by appropriate analysis and, if necessary, structures must be reinforced in accordance with the results of the analysis.

Such analyses must be guided by the requirements of standards and safety conditions.

Analysis methods are based on the ability of the system to accept loads even if one of the key connections is lost.

It is obvious that ignoring the requirements for resistance to progressive collapse can lead to the complete failure of the load-bearing structures and the building as a whole: (Fig. 2, a).

Increasing the strength and stiffness of structures based on the requirement of keeping the bearing capacity and suitability for normal maintenance: (Fig. 2, b). This option requires maximum capital investment after any emergency impact.

A compromise approach is more economical, where the bearing capacity is preserved after an emergency impact, but the suitability for normal maintenance is not ensured: (Fig. 2, c).

The approach proposed in the article and implemented in LIRA-SAPR allows to simulate in various ways an emergency or force majeure situation (Fig. 2, c) so as to ensure the possibility of emergency evacuation of people during the time until the local collapse develops into a progressive one. The structures are designed in such a way that in an emergency situation the life preservation of the building residents is guaranteed. The analysis in LIRA-SAPR takes into account the effects of force redistribution and adaptability of structures and their operation in the pre-design phase [6, 7].

Several analysis options are implemented in the LIRA-SAPR software package

1. Quasi-static staging:

- Linear analysis
- Nonlinear analysis

2. Dynamic staging:

- Linear analysis
- Nonlinear analysis

In the quasi-static staging, there are two common approaches: pushdown and pulldown. For example, the U.S. standards for progressive collapse (UFC 4-023-03-2016, GSA2003-2016) for quasi-static analyses, it is common to use a partial pushdown analysis that assumes increasing loads on horizontal structures adjacent to the chain of columns above the column being removed; and for nonlinear dynamic analyses, use a partial force pulldown analysis that multiplies the forces acting in the element being removed with the opposite sign by the dynamic factor.

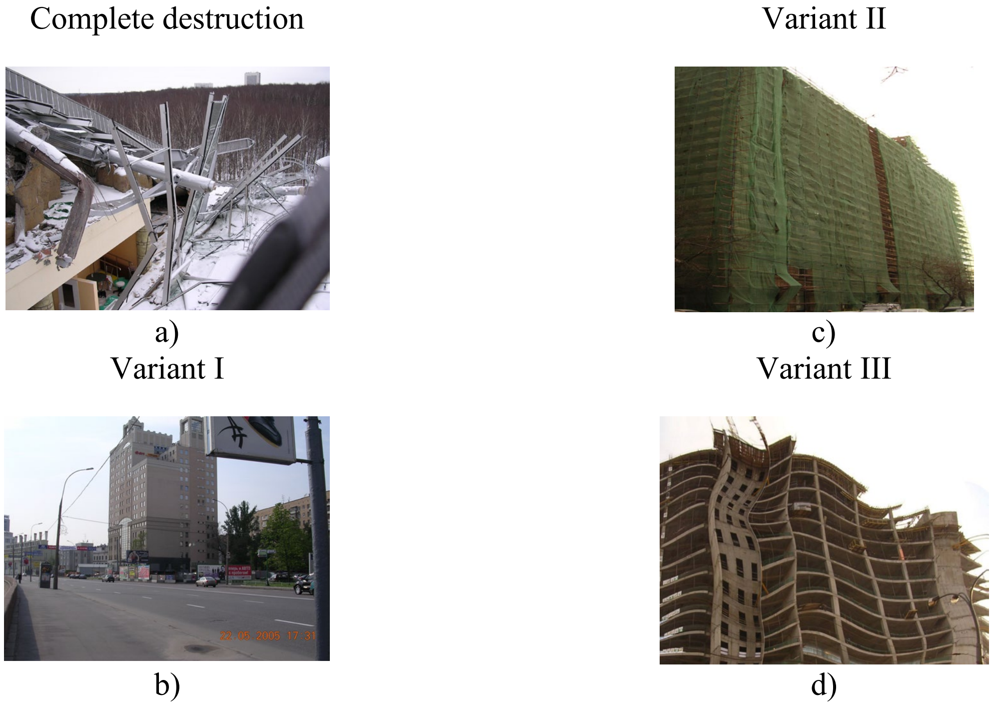


Fig. 2. Variants of the consequences of accidental impacts

In domestic practice, it is common to use a partial force pulldown analysis. But at the same time in the papers of famous domestic scientists, pushdown is applied.

Why does it matter? The two approaches are not equivalent in their results, and the dynamic factors used in the two approaches are not equal. However, in LIRA-SAPR the pulldown analysis scheme is automated (Fig. 3).

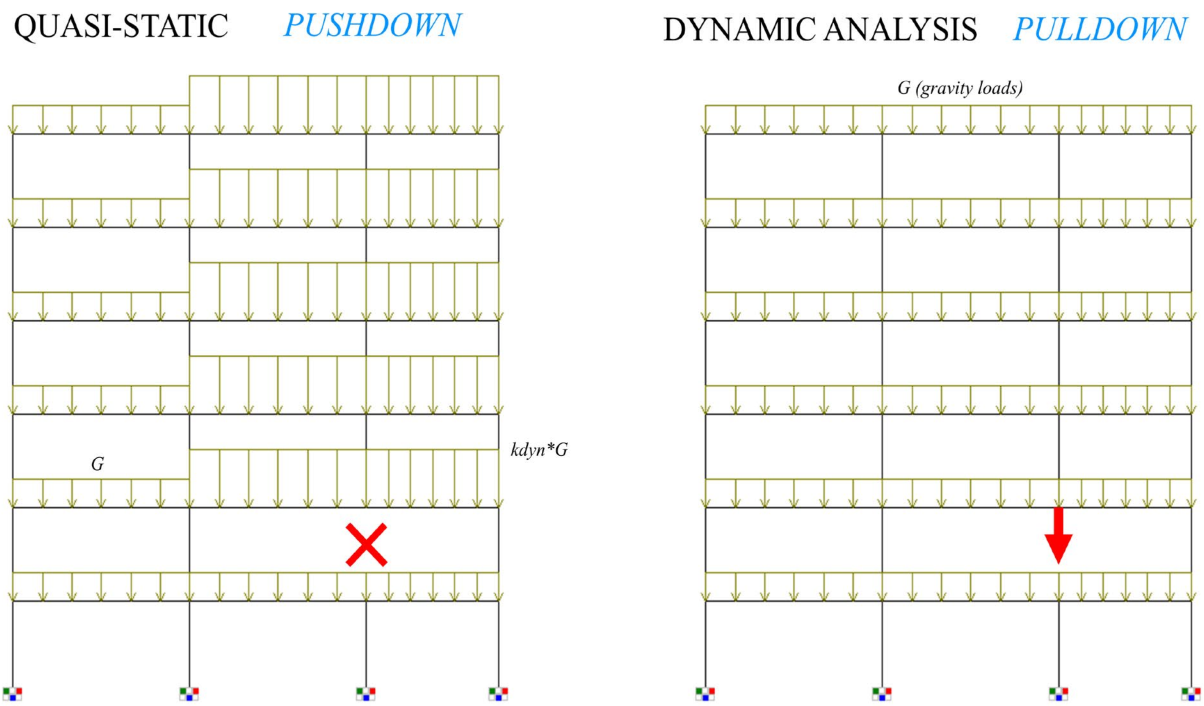


Fig.3. Approaches to solving the problem

The Dynamics of the Process

Obviously, these types of loads can have a dynamic component. This applies to shock, seismic, explosive impacts. This also applies to the sudden removal of supports. Many design models have been developed which take into account the dynamic nature of the load on the structure. The peculiarity of the problem of resistance to progressive fracture in a contact explosion is that in the initial moment the system has quite elastic properties, and in the process of deformation it becomes elastoplastic and even plastic [8]. The problem has no universal solution. Here we will limit ourselves to the information that when falling on an elastic body, the dynamic factor is equals 2. When falling on a plastically deformed body, the dynamic factor equals 1; when the body in the process of deformation passes from the elastic to the plastic state, the dynamic factor acquires an intermediate value.

In LIRA-SAPR it is possible to set the dynamic factor (Kd) to simulate the local failure of the structural elements. It is assigned to nodes separately for all degrees of freedom. Therefore, you can, for example, set it to 2 on axis Z, and on other degrees leave 1 or another value. Thus, the decision on the value of dynamic factors in any direction is made by the engineer.

By default, a factor of 1 is written in all nodes. There is a mosaic to visualize the assigned Kd values.

The peculiarity of this implementation is that the given factor is triggered only in those nodes that belonged to elements disassembled in the last stage (in other stages you can disassemble elements as before, such as temporary supports, etc.). Exceptions are nodes that have become "hanging", i.e. not attached to anything, as a result of disassembly. Thus, you can assign to all nodes of the scheme adopted for the analysis dynamic factor, and it will work only in the right place (Fig. 4).

Such a flexible tool, where everything is decided by the user, we made primarily because there are no clear methodological guidelines on how to make this analysis. The standards are changing. There is a lack of unambiguity in this question. For example, is it necessary to assign a dynamic factor of 2 to the node under the remote column? It is easy to see that in the general case kd for the node under the remote column is not equal to kd for the upper node.

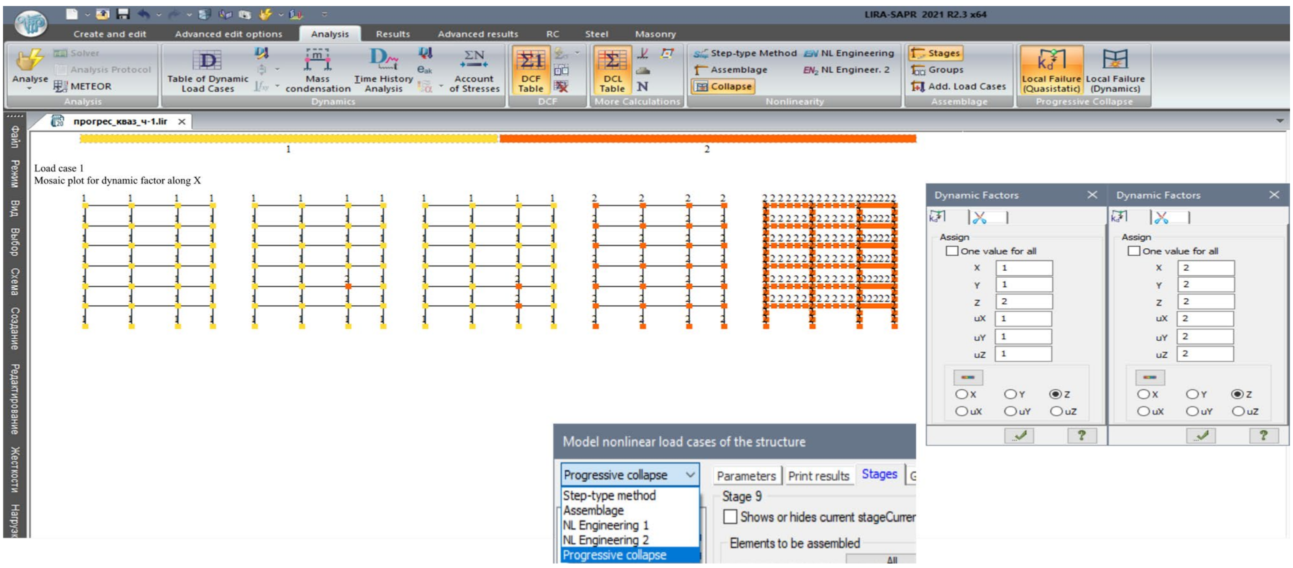


Fig. 4. Quasi-static staging in LIRA-SAPR

Note - the reactions from the removed elements occurred only in the nodes (Fig. 5) to which the removed elements were adjacent, regardless of the nodes to which Kdin was assigned.

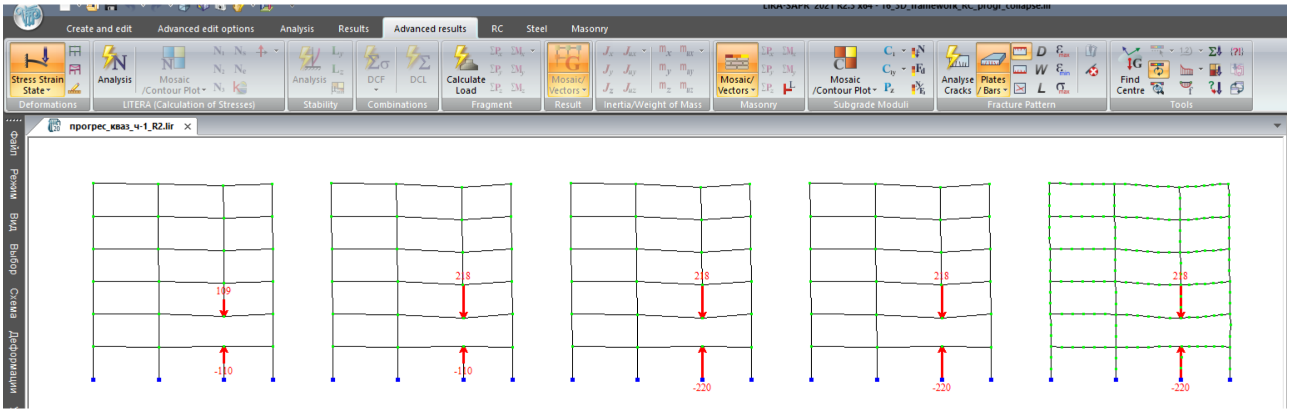


Fig.5. Result of simulation of local failure in quasi-statics (reactions in nodes)

An important factor in the reaction of the structure to the instantaneous application of the load is the plasticity of the structure in the limiting stage of work, i.e., the presence of the plastic work area of the element section or the connection node of the structural elements.

The above makes it possible to imagine that the problem does not have a one-size-fits-all solution. It can be based on a huge variety of achievements of construction mechanics and theory of structures and is in many ways a design problem: a combination of intuitive reasoning and clear theoretical proofs. Therefore, it is very important to take into account the nonlinear operation of structures.

Conclusions

Application of different types of nonlinearity allows to take into account some factors of operation of structures, and to receive correct forces in its elements (especially taking into account similar extreme influence, when in comparison with an operational mode, the character of operation of structures essentially changes). Hence the requirement of the standards: "The calculation shall be made taking into account the significant effects of physical, geometric, and structural nonlinearities in the failure/collapse of individual parts of structures".

1. Taking into account geometric nonlinearity allows you to get in the process of step analysis eccentricity to vertical loads. In the presence of a significant tilt of the structure, this can lead to a significant change in the stress-strain state of the structure (which in turn will further increase the tilt of the structure).
2. Taking into account the geometric nonlinearity allows you to change the nature of the work of some structures in an attempt to adapt to the changed working conditions: "At large deflections of the slabs should be considered their work as the work of the elements of the hanging system. In this case, it should be ensured the constructive ability to absorb the arising horizontal forces".
3. The consideration of physical nonlinearity makes it possible to obtain redistribution of loads between structural elements, taking into account the actual stress-strain state of their sections in accordance with the given work diagrams.
4. Consideration of structural non-linearity (single-sided supports, platform and contact joints, etc.).

But this is all, of course, mandatory for situations where such factors of operation of a particular structure are present, i.e., "taking into account significant effects", if they are present in a particular analysis.

The current state of design, construction and maintenance of civil buildings and complex engineering facilities has dangerous trends: complexity is increasing and projects are often carried out by specialists with powerful computing systems, but they do not have enough knowledge to qualify non-standard systems. The proposed article should draw the attention of specialists to the need to improve the culture of design and to master new tasks designed to ensure safety in the field of construction.

References

[1] EN 1991-1-1:2002 Eurocode 1: Actions on structures.

[2] A.A. Komarov Razrusheniya zdanij pri avarijnykh vzryvakh bytovogo gaza (Destruction of buildings in domestic gas explosions). Pozharovzryvobezopasnost` (Fire and explosion safety). 9 (2006).

[3] N.N. Popov, B.S. Rastorguev, Raschet konstrukczij speczial`nykh sooruzhenij (Analysis of special structures) M. Stroyizdat, 1990.

[4] V.O. Almazov, Soprotivlenie progressiruyushhemu razrusheniyu v mnogoetazhnykh karkasakh ramnogo tipa. (Resistance to progressive collapse in multi-storey frame-type frameworks), Vysotny`e i bolsheproletnye zdaniya. Tekhnologii inzhenernoj bezopasnosti i nadezhnosti (seminar) (High-rise and overspan buildings. Engineering safety and reliability technologies (seminar)). MNBU. Moscow, 2004.

[5] EN 1992-1-1:2004 Eurocode 2: Design of concrete structures.

[6] M.S. Barabash, P.N. Kir`yazev, M.A. Romashkina, Chislennoe modelirovanie napryazhenno-deformirovannogo sostoyaniya kirpichnogo zhilogo zdaniya pri vzryve bytovogo gaza vnutri pomeshheniya (Numerical simulation of the stress-strain state of a brick residential building in a domestic gas explosion indoors), International Journal for Computational Civil and Structural Engineering. 12 (1) (2016) 73–85.

[7] M.S. Barabash, V.M. Pershakov, A.O. Byelyatins`kij, K.M. Lisnicz`ka, Problemi protidi`yi konstrukczi`j progresuyuchomu obvalennyu budi`vel` ta sporud (Problems of counteraction of structures to progressive collapse of buildings and structures), Budi`vnicztvo Ukrayini. 4. (2015) 28–31.

[8] M. Barabash, Some aspects of modelling nonlinear behaviour of reinforced concrete, Strength of Materials and Theory of Structures. 100 (2018) 164–171.

Advances in Science and Technology
ISSN: 1662-0356, Vol. 114, pp 27-39
doi:10.4028/p-7tt2j8

Submitted: 2022-04-20
Accepted: 2022-04-26
Online: 2022-07-29

Application of UAV Video Communication Systems During Investigation of Emergency Situations

MALADYKA Ihor[1,a*], STAS Serhiy[1,b], PUSTOVIT Mykhailo[1,c], DZHULAY Oleksandr[1,d]

[1]Cherkasy Institute of Fire Safety Named After Chernobyl Heroes National University of Civil Defence of Ukraine, 8, Onoprienko str., Cherkasy, Ukraine, 18034

[a]maladyka_ihor@chipb.org.in, [b]stas_serhii@chipb.org.in,

[c]pustovit_mykhailo@chipb.org.in, [d]dzhulai_oleksandr@chipb.org.in

Keywords: unmanned aerial vehicle, emergency, video communication.

Abstract. The appearance in widespread use of unmanned aerial vehicles, both multi-rotor and wing-carrying aircraft, revealed the possibility of their use in the activities of the State Emergency Service of Ukraine. They can be used for emergency reconnaissance, aerial surveying, search operations, aviation chemical work related to the circulation of hazardous substances, monitoring of territories and objects, transmission of radio signals, delivery to the site of emergencies various types of payload, conducting alerting, lighting emergency situations and direct firefighting. Therefore, the issue of using unmanned aerial vehicles in the activities of the State Emergency Service of Ukraine is relevant.

In essence, the use of an unmanned aerial vehicle is reduced to two main types of work - observation or work around a point object or movement over long distances to ensure work on the earth's surface. It is clear that the technical characteristics of the unmanned aerial vehicle determines its suitability for use in the relevant types of work.

One of these characteristics is the range of radio communication, the busiest channel of which is real-time video communication, which is essential for most assigned tasks.

The article attempts to estimate the range of video data transmission by radio for the most common models of multi-rotor unmanned aerial vehicles of mass production and video data transmission systems that can be used optionally. To this end, we analyze the characteristics of video transmission systems, factors that affect the quality of video communication and others. Existing mass-produced models are best suited to work around a point object. Their use for long-distance flights will be limited by the range of video data transmission.

By overcoming this situation, the authors see the use of unified unmanned aerial vehicles equipping them with optional video transmission systems.

1 Introduction

Issues related in one way or another to unmanned aerial vehicles (UAVs) have become increasingly important in recent years, due to a number of objective reasons.

The spectrum of existing and developed aircraft is very wide and ranges from micro and mini - UAVs, to heavy multi - ton aircraft, and UAVs capable of performing long range and ultra-high-altitude flights lasting up to several months. In addition, the appointment of modern UAVs is not limited to the military sphere. The sphere of their civil application is rapidly expanding (in such areas as the oil and gas industry, transport, construction, agriculture, communications, etc.), which provides additional impulses to the development of unmanned aerial vehicles.

In many countries, both large companies and small specialized enterprises, university departments and even some amateur enthusiasts are engaged in the development of unmanned aerial vehicles.

Modern conditions of operative actions on emergency situations responding have strengthened requirements to completeness of information support of operative actions management processes. As a result, the requirements for aviation systems as providers of information on emergencies are expanding [1], [2]. At the same time, the issues of aviation systems application as an active element that ensures stable, continuous, operational functioning of the control system in emergency situations are investigated.

The primary task of any communication system is to provide the required communication range. However, the range of communication in the VHF band is limited by the properties of radio waves to bypass the curvature of the earth's surface.

The vast majority of UAVs exchange information and telemetry data with the ground control station via radio channels. When conducting surveillance with UAVs, you can use several modes of operation, one of them is recording the event on electronic UAVs with subsequent playback after returning it to the take-off point, which is quite inconvenient when performing operative actions. The most convenient way to obtain photo and video data is real-time monitoring, which involves the transmission of video signals in various formats over the air. The limitation of this method is, after all, the significant amount of information that is transmitted. This leads to high requirements for the systems of receiving and transmission of such information and forces UAV manufacturers to make technical and economic compromises.

The aim of the article. Highlight the restrictions on the use of serial unmanned aerial vehicles in the activities of the State Emergency Service of Ukraine and possible ways to universalize them.

2 Main Part

The risks of emergencies of natural and technogenic nature in Ukraine, despite the application of precautionary measures, are not decreasing every year.

According to estimates by the International Institute of Strategic Researches, today more than 30 countries are developing, manufacturing and using multifunctional UAVs. The number of countries and their fleet of unmanned aerial vehicles is growing every year.

The data obtained from the UAV, in addition to providing an opportunity to analyze and assess the situation, will allow you to make operative management decisions. Thanks to this, emergency rescue units will be able to take measures to prevent or eliminate emergencies in the shortest time.

Tasks that can be solved by UAVs in the system of the Civil Service of Ukraine for Emergencies:

- performing emergency reconnaissance, aerial surveying of the area, performing search operations;
- performing of aviation chemical works related to the circulation of hazardous substances;
- monitoring of territories and objects;
- transmission of radio signals;
- delivery to the place of emergency various kinds of payload; notification, lighting the place of emergency;
- remote sensing of fires and places of their probable occurrence, and direct extinguishing of fires.

As can be seen from Table 1 and Figure 1, about half of UAVs are related to fire-fighting reconnaissance and training, most of which are UAVs involved in real fires, which makes this topic relevant.

In the territorial divisions of the State Emergency Service of Ukraine in accordance with paragraph 3.2 of section III of the Rules of registration of state aircraft of Ukraine [3] in the SES issued an order to allow the operation of unmanned aerial vehicles [4]. According to the order, the following UAVs were allowed to operate: DJI Phantom 2, DJI Phantom 2 Vision; DJI Phantom 3 Professional, DJI Phantom 3 SE; DJI Phantom 4, DJI Phantom 4 Pro V2.0, DJI Phantom 4 GL300E, DJI Phantom 4 Advanced and Hubsan H502S FPV. The next order of the SES [5] allowed the UAVs DJI Matrice 100, DJI Matrice 200, DJI Matrice 210 to operate; DJI Mavic Air, DJI Mavic 2 Zoom and Yuneec Typhoon H.

Table 1. Involvement of UAVs by units of the SES of Ukraine in 2021

Area Name	Fire	Emergency	Training	Other	Total
Vinnytsia region					
Volyn region					
Dnipropetrovsk region	2		6	21	29
Donetsk region		1	6	20	27
Zhytomyr region			4	12	16
Zakarpattia region		1	3	3	7
Zaporizhzhia region			1	5	6
Ivano-Frankivsk region	11		12	36	59
Kyiv	7		1	67	71
Kyiv region	10			110	120
Kirovohrad region	1		1	6	8
Luhansk region	9		34	33	76
Lviv region	6		8	13	27
Mykolaiv region	76	3	11	81	171
Odesa region			6	7	13
Poltava region	1		2		3
Rivne region	132		42	18	192
Sumy region	1		1	1	3
Ternopil region	5		36	15	56
Kharkiv region					
Kherson region	34	4	7	41	85
Khmelnytsky region					
Cherkasy region	2	1	4	16	23
Chernivtsi region	1	4	11	10	26
Chernihiv region	8	2	7	2	19
Total	304	16	205	476	954

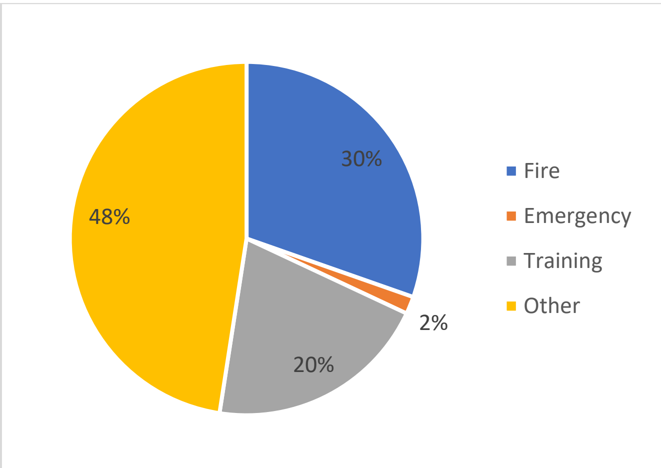


Fig. 1. Involvement of UAVs by units of the SES of Ukraine in 2021

Reconnaissance with the use of unmanned aerial vehicles is a process of periodic or continuous collection of information about the nature and parameters of the reconnaissance object to determine trends in its state.

Depending on the problem to be solved, the unmanned aerial vehicle can be equipped with appropriate technical means for its implementation, such as cameras, thermal imagers, multispectral cameras, laser scanners, gas analyzers, radiation or chemical reconnaissance devices, radar stations etc.

The main practical methods of using UAVs in emergency reconnaissance are:
- monitoring of the area (sector) of airspace with one pass on a given route;
- monitoring of the area (sector) of airspace with several passages along a given route;
- monitoring of a given area with one passage over the object;
- monitoring of a given area with several passages over the object;
- constant monitoring of the object;
- periodic passages over the object;
- combing the area.

For general reconnaissance, a closed circular route is the most appropriate. The main advantages of this method are the coverage of a large area, efficiency and speed of reconnaissance, the ability to survey hard-to-reach areas, relatively simple planning of the flight task and prompt processing of the results. The flight route must provide an overview of the entire work area. For the rational use of UAV energy resources, the flight route should be laid in such a way that the first half of the UAV flight takes place against the wind.

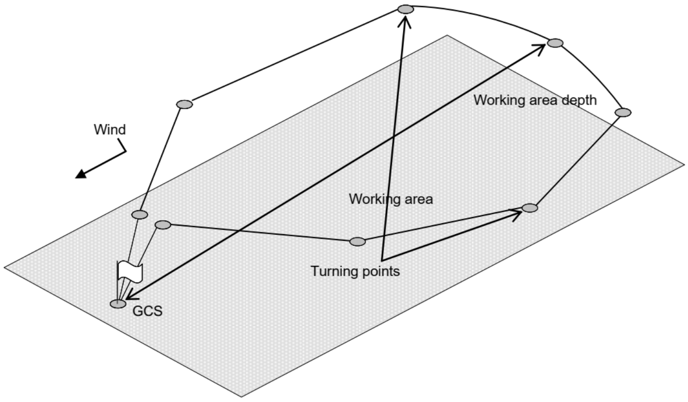


Fig. 2. Ring closed route

The main ways of continuous inspection of the area during reconnaissance and search operations are "combing", "shifted turn". Varieties of combing the terrain are tack (parallel, converging and diverging), box (converging, divergent), with which the terrain of a given area is subject to continuous review during the horizontal flight of UAVs (Figures 3 - 5).

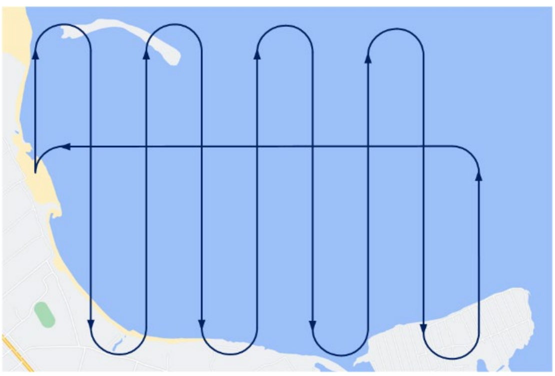


Fig. 3. Method of finding and planning the route "Parallel tack"

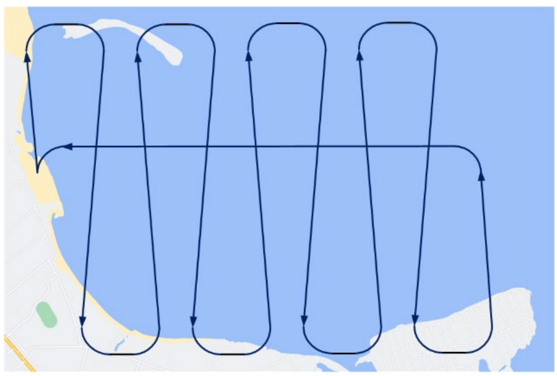


Fig. 4. Method of finding and planning a route "Converging tack"

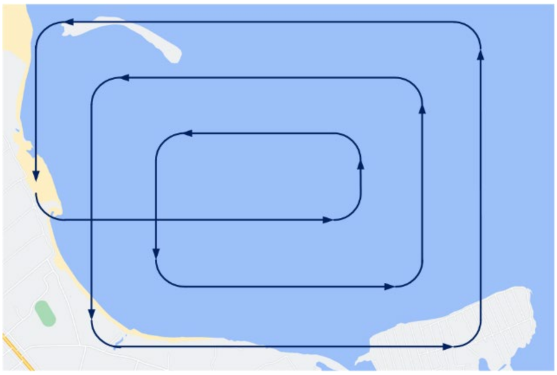


Fig. 5. Method of search and planning route "Diverging box"

The use of UAVs in reconnaissance on long stretches of land, water and ice is generally limited to conducting aerial reconnaissance tasks of linear objects, given the considerable distances that UAVs must cover.

Exploration of long sections of the earth's surface can be used to control linear objects in conditions that ensure their unambiguous state or direction of movement, such as the state of pipelines; power lines; roads, traffic jams on highways; conducting search and rescue operations along the coastline, etc. [2].

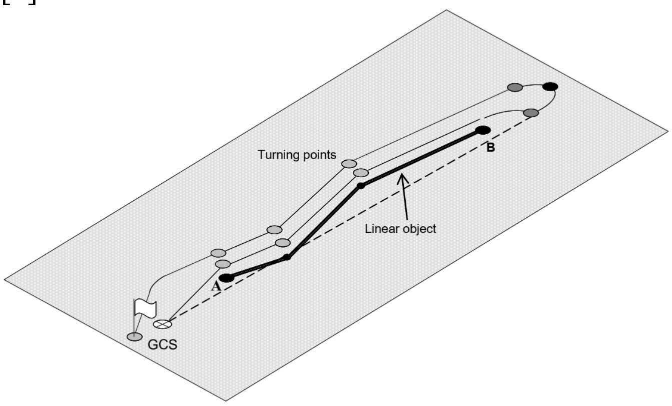


Fig. 6. Overflight of a linear object

Reconnaissance of a point object can be carried out with the help of aircraft and multi-rotor UAVs. Depending on the type of UAVs, the methods of their use differ.

Exploration of a point object is carried out from heights that ensure sufficient completeness and reliability of the information received about the object and the necessary accuracy of determining its coordinates. When visually searching (using video cameras and IR cameras) aircraft UAVs fly at an altitude of 500-600 m, multi-rotor - at an altitude of 200-300 m above the terrain (obstacles, water surface). Flight altitude can be specified depending on the characteristics of the reconnaissance area, the range of radio visibility between the ground control station and UAV, meteorological conditions, the level of training of the operator (external pilot) and the range of detection of various objects in the field [1].

Depending on the type of target payload, UAVs can reconnoiter a point object by video and aerial photography of the object from different heights, thermal imaging monitoring, measurement of radiation pollution, detection of gas leaks, quantification of their concentration, temperature and pressure measurement, etc.

For example, the flight of a given object can be carried out using any type of UAV, due solely to the duration of the flight and speed. Used when inspecting specific objects. Widely used in cases where the coordinates of the object are known and need to clarify its state (Fig. 7).

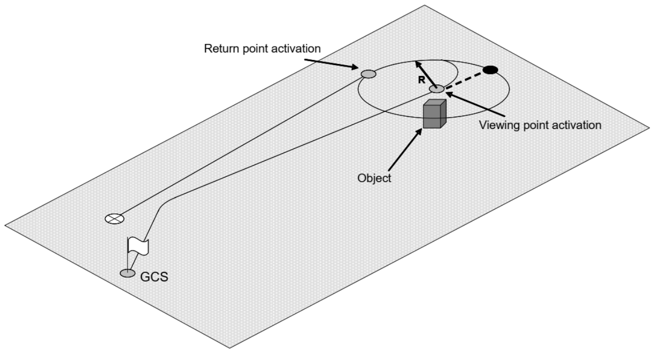


Fig. 7. Overflight point object

Another way to use a UAV can be to use it as a point of observation.

UAVs, with the appropriate target load, can provide a wide field of observation both during the day and at night. If necessary, such an observation post can be quickly deployed in the desired direction, and quickly moved to another - in contrast to stationary solutions such as observation towers and masts (Fig. 8).

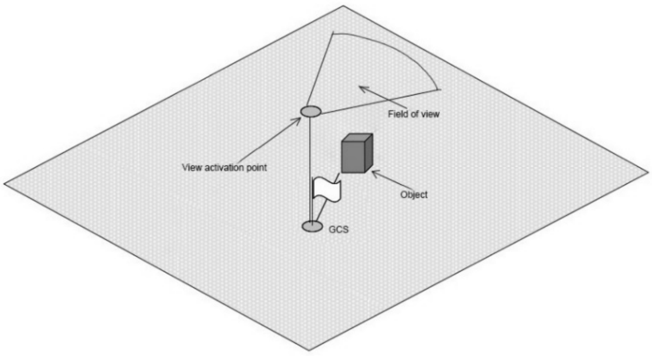


Fig. 8. Hanging at a point for reconnaissance

To date, the SES uses UAVs, the list of which is given above. Manufacturers are constantly updating their UAVs with new models with improved capabilities, including increased video range. Given the trends, it is possible to use the latest developments in the future in the units of the SES. Tables 2 and 3 show the characteristics of serial production UAVs.

Table 2. Characteristics of video communication UAVs of serial production

UAV model	Producing country	Frequency, [GHz]	Transmitter power, [mW]	Signal level, [dBm]	Video communication range , [km]
DJI Matrix 300	China	2.400-2.483	900	29.5	15
		5.725-5.850	700	28.5	15
DJI Matrix 200	China	2.400-2.483	400	26	8
		5.725-5.850	650	28	8
DJI Mavic 3	China	2.400-2.483	2000	33	15
		5.725-5.850	2000	33	15
DJI Mavic 2 Pro	China	2.400-2.483	400	26	10
		5.725-5.850	400	26	10
Phantom 4 Pro	China	2.400-2.483	400	26	7
		5.725-5.850	650	28	7
Autel Here are 2	USA	2.4 - 2.4835	500	27	9
Yuneec Typhoon H3	China	5.725-5.850			2
Hubsan ZINO Mini Pro	China	5.725-5.850	400	26	10
Parrot ANAFI Thermal	France	2.400-2.483			4
		5.725-5.850			4

Table 3. Characteristics of video communication UAVs of serial production

UAV model	Codec	Bitrate, [MB/s]	Video resolution, [px]	Frame rate, [fps]	Delay, [ms]
DJI Matrix 300	H.264 / H.265		3 x 1920x1080	60	
DJI Matrix 200	H.264 / H.265		1920x1080	30	
DJI Mavic 3	H.264 / H.265	80	1920x1080	60	120
DJI Mavic 2 Pro	H.264 / H.265	40	1920x1080	30	130
Phantom 4 Pro	H.264 / H.265		1280x720	30	220
Autel Here are 2	H.264 / H.265	40	1920x1080	30	
Yuneec Typhoon H3	H.264 / H.265		1280x720	30	
Hubsan ZINO Mini Pro	H.265	20	1920x1080	30	200
Parrot ANAFI Thermal	H.264	5	1280x720	30	280

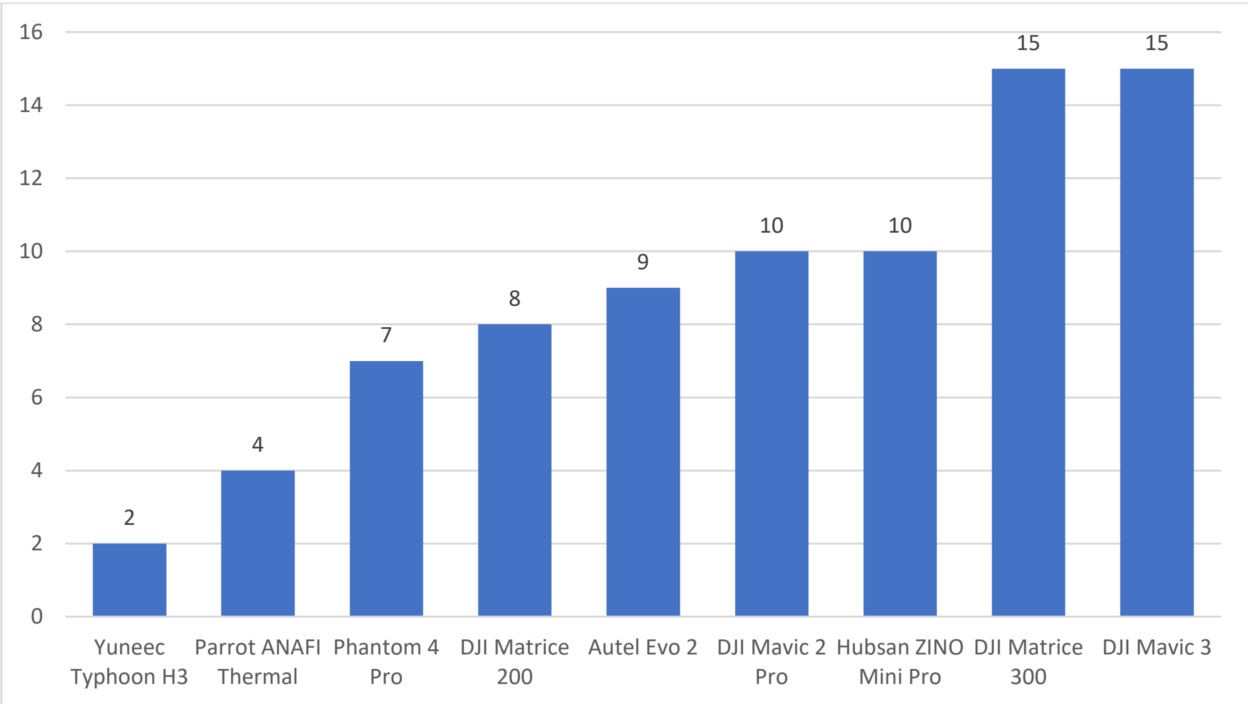


Fig. 9. Range of video communication of serial UAVs

As you can see from Figure 9, the latest generation of DJI UAVs, which are specialized products for commercial use, can provide the longest video communication range, but due to their high cost, they have not become widespread in the SES.

In addition to the use of serial UAVs with integrated video communication systems, a common way to organize video communication with UAVs is the use of third-party systems created both on the basis of specialized solutions and on the basis of universal computer solutions. The characteristics of such systems are given in tables 4 and 5.

Table 4. Characteristics of serial video communication systems for UAVs

Model name	Producing country	Frequency, [MHz]	Transmitter power, [mW]	Signal level, [dBm]	Video communication range, [km]
Insight 5G	China	5100 - 5825	200	23	5
Insight Pro	China	5100 - 5825	200	23	5
Herelink Long Range HD	Great Britain	2.4			20
Siyi HM30	China	5100 - 5825	320	25	30
Suntor ST30HPT	China	2.402-2.478			30
CONNEX mini	Israel	5100 - 5825			1
LinkAV -1614	China	300 - 2,700	1000	30	20
OpenHD	international community	2.400-2.483	500	27	50
		5100 - 5825			
RubyFPV	international community	2.400-2.483	500	27	45
		5100 - 5825			

Table 5. Characteristics of serial video communication systems for UAVs

Model name	Codec	Bitrate, [MB/s]	Video resolution	Frame rate	Delay, [ms]
Insight 5G	H.264		1920x1080	30	80
Insight Pro	H.264		1920x1080	60	60
Herelink Long Range HD	H.264		1920x1080	60	110
Siyi HM30	H.264 / H.265		1920x1080	60	150
Suntor ST30HPT	H.264	12	1920x1080	60	70
CONNEX mini			1920x1080	60	<1
LinkAV -1614	H.264		1920x1080	30	80
OpenHD	H.264 / H.265	15	1920x1080	30	130
RubyFPV	H.264 / H.265	13	1920x1080	30	110

As can be seen from Figure 10, the maximum video communication range of such systems is 45-50 km, which is many times higher than integrated video communication systems of serial production UAVs of the highest price category.

The key to real-time video communication is the amount of data being transmitted. Table 6 shows the difference between the transmission rates of compressed and uncompressed data. H.265 encoding reduces data transfer speeds and saves bandwidth. Currently, H.264 encoding, which is the most common format for recording, compressing and transmitting video content, is a huge step forward in improving video compression technology and one of several possible successors to the widely used AVC format (H.264 or MRES-4 part 10).

For example, when using the 1080p format, the compressed data transfer rate is 14.93 Mbps. data at this speed is easy to control wirelessly and with a baseband processor.

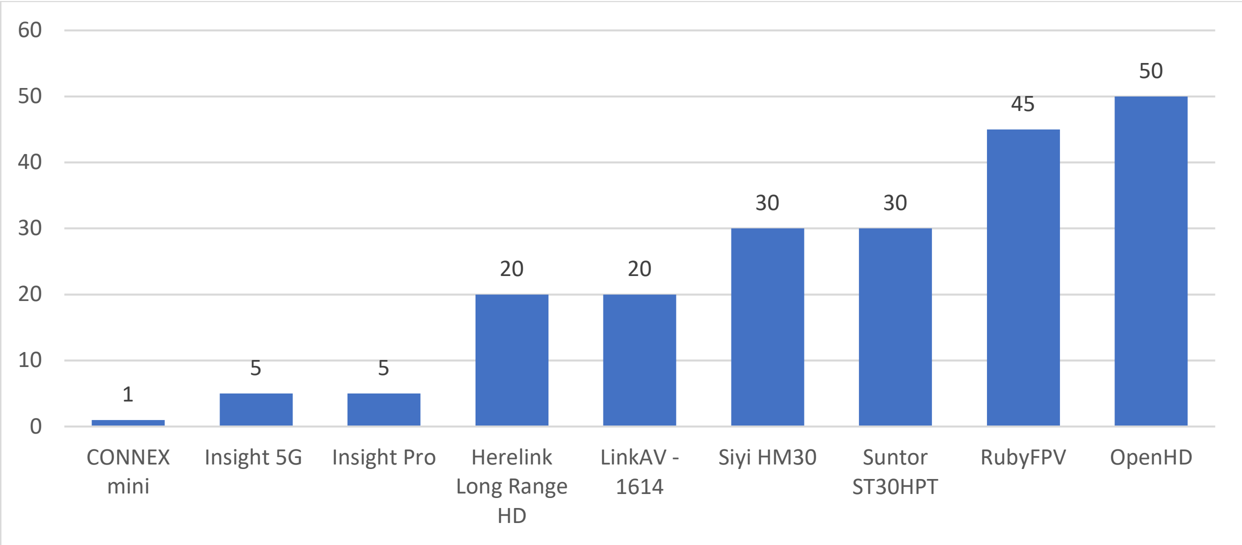


Fig. 10. Video communication range of individual systems

Table 6. Transmission rates of compressed and uncompressed data

Format	Number of horizontal lines	Number of lines vertically	Pixels	Uncompressed data transfer rate, [Mbit / s]	Compressed data transfer rate, [Mbit / s], k $_{compression}$ 200	QPSK Signal bandwidth, [MHz]	16 QAM Signal bandwidth, [MHz]	64 QAM Signal bandwidth, [MHz]
VGA	640	480	307200	442	2.2	1.375 th most common	0.6875	0.4583
720p	1280	720	921600	1328	6.64	4.1250	2.0625	1.3750
1080p	1920	1080	2073600	2986	14.93	9.3125	4.6563	3.1042
2k	2048	1152	2359296	3400	17.0	10.6250	5.3125	3.5417
4k	4096	2160	8847360	12740	63.7	30.8125	19.9063	13.2708

Real-time video broadcast during reconnaissance from the UAV is conducted to the ground control station, usually in the ultra-shortwave or ultra-high frequency range, which is characterized by the aircraft in the "line of sight" of radio waves in space. The maximum range of video transmission depends on the specific characteristics of the UAV complexes used, for example, at frequencies of 2.4 GHz, it is about 10-15 km (Fig. 11).

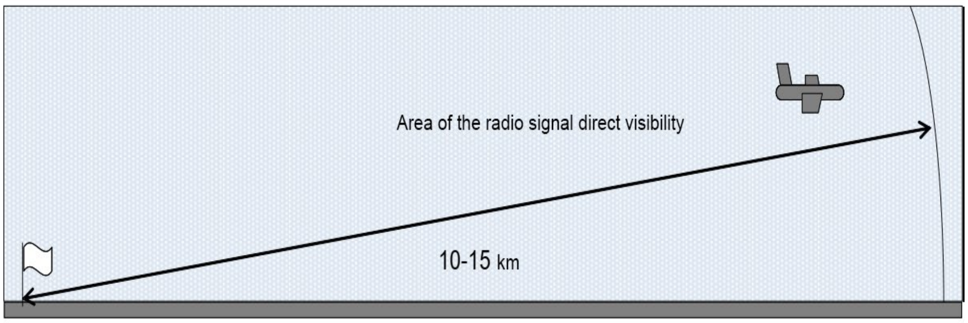


Fig. 11. Area of the radio signal direct visibility

In the flight zone of the UAV there may be obstacles that create a "dead zone" for receiving radio waves, this must be taken into account when planning the route and altitude of the flight (Fig. 12).

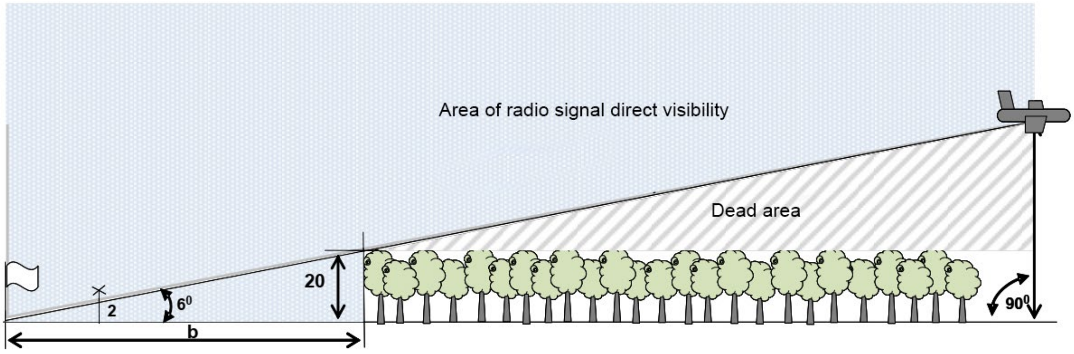


Fig. 12. Dead area of the radio signal

The maximum range of radio communication is defined as [6]:

$$r_0 = 3.57\left(\sqrt{h_1} + \sqrt{h_2}\right)$$

where
r_0 - maximum radio range, km;
h_1 - lifting height of the first antenna, m;
h_2 - lifting height of the second antenna, m

As a rule, the GCS antenna is mobile and is installed at a height of not more than 10 m. Figure 13 shows the dependence of the maximum radio range on the flight altitude of UAVs at certain specified heights of the GCS antenna.

As can be seen from Figure 13, the dependence of the maximum communication range on the lift height of the GCS antenna is weak, so the height of the mast for terrestrial antenna is determined by the need to reduce the impact of multipath, taking into account possible obstacles to signal propagation (terrain, buildings) [7] .

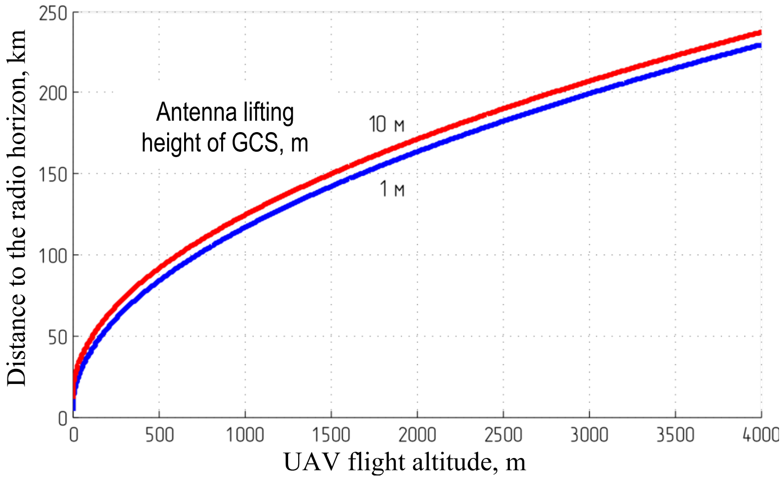


Fig. 13. Maximum communication range depending on the height of the UAV and GCS antennas

For UAVs operating to ensure operational action, the maximum range of video transmission is a critical parameter. However, it is essential that the connection is not lost even over a limited distance when propagating in the air with water vapor (fog, clouds), rain, snow and other obstacles that may weaken the signal.

The sensitivity of the receiver is usually determined by the minimum level of input signal S_{min}, which is required for demodulation or recovery of information from the transmitter. Knowing the magnitude of the sensitivity, you can calculate the maximum transmission range as follows:

$$S_{min} = 10lg\,(kT_0 BW) + NK + (S/N)_{min} =$$
$$= -174\text{ dBm} + 10lg\,BW + NK + (S/N)_{min},$$

where $(S/N)_{min}$ - the minimum ratio of signal to noise required for signal processing;
NK - noise figure of the receiver;
k is the Boltzmann constant equal to $1.38 \cdot 10^{-23}$ J / K;
$T_0 = 290$ K - absolute temperature at the inlet of the receiver;
BW - bandwidth of the receiver, Hz .

The value $(S/N)_{min}$ depends on the order of modulation or demodulation. With constant S/N errors are lower with a relatively small order of modulation, and with the same number of errors for demodulation requires a large value of S/N with a higher order of modulation. Thus, if the transmitter is far from the receiver, the signal becomes weaker, and the value of S/N does not allow to implement higher-order demodulation. To avoid this and ensure that the video signal is transmitted at the same speed, lower order modulation is used by increasing the bandwidth. Due to this, the image does not blur.

Software-defined radio systems with digital modulation and demodulation have the ability to change the order of modulation. The greater the radio frequency power at a fixed antenna gain, the greater the communication range using a fixed sensitivity receiver. However, the amount of maximum power transmitted must meet the requirements of FCC/CE standards.

In addition, the carrier frequency affects the transmission range. When the wave propagates in free space, there are losses due to the dispersion, which is determined as follows:

$$L_{disp} = 20lg\frac{4\pi R}{\lambda} = 20lg\frac{4\pi Rf}{c}$$

where R - distance;
λ - wavelength;
f - frequency;
c - speed of light.

Thus, the higher the signal frequency, the greater the loss at constant communication range in free space. For example, at a carrier frequency of 5.8 GHz, the attenuation of the signal will be approximately 7.7 dB more than when it travels the same distance at a frequency of 2.4 GHz.

2.4 GHz is widely used for Wi-Fi, Bluetooth and IoT, which often overloads channels. Working on this frequency to transmit video and control signals increases the likelihood of interference and unstable operation, which is undesirable in the case of UAVs.

Switching to another frequency band provides more reliable data transmission and communication control. As soon as the transmitter detects an overloaded frequency range, it automatically switches to using another band. Adaptive choice of carrier frequency or channel in the operating mode is one of the most necessary functions of modern UAVs.

Depending on the operating range of UAVs, as the GCS antenna are used either high-directional antenna or low-directional antennas. For antennas with high SWR it is necessary to use a rotary support device and a UAV tracking system, as the width of the main lobe of the pattern of such antennas is usually less than 10°. As ground equipment does not have strict requirements for mass and size characteristics, the use of a scanning digital antenna array as an GCS antenna is not always justified due to its high cost, except for the use of an antenna array for simultaneous observation of several UAVs .

The communication range is also determined by such an antenna parameter as the gain, measured in dBi. Gain is an important parameter because it takes into account:

- the ability of the antenna to focus the energy of the transmitter in the direction of the receiver compared to the isotropic emitter (isotropic, hence the index i dBi);

- losses in the antenna itself [6,8].

To increase the communication range, it is necessary to choose antennas with the maximum possible value of the gain from those that are suitable for the mass and size parameters and capabilities of the video communication system.

The most effective on-board antenna devices for the UAV mini-class are omnidirectional antennas with circular polarization, but low power and low gain.

The longest communication range for terrestrial antenna systems can be achieved by using high-efficiency antenna arrays that have high radiation efficiency by minimizing losses in the switchgear.

Failures in the electromagnetic field strength occur due to the addition of antiphase in the location of the GCS antenna direct and reflected from the Earth's surface signal.

Such oscillations of the signal on the GCS can be eliminated by fulfilling 2 conditions:

- use a modem with at least two reception channels (RX diversity) at the GCS;
- place the receiving antennas on the mast of the GCS at different heights.

The diversity of the heights of the receiving antennas must be made so that the dips in the field strength at the location of one antenna are compensated by levels above the sensitivity of the receiver at the location of the other antenna.

When choosing the frequency of video communication lines, it is also necessary to take into account the attenuation of the signal during propagation in the Earth's atmosphere. For GCS-UAV video communication lines , the attenuation in the atmosphere is caused by gases, rain, hail, snow, fog and clouds [9]. For operating frequencies below 6 GHz, attenuation in gases can be neglected. The strongest weakening is observed in rains, especially high intensity (showers). Table 7 shows the data [9] on attenuation [dB/km] in rains of different intensities for frequencies 3-6 GHz.

Table 7. Attenuation of radio waves [dB/km] in rains of different intensity depending on the Frequency

Precipitation level	Frequency, [GHz]			
	3	4	5	6
3 mm / h (weak)	$0.3 \cdot 10^{-3}$	$0.3 \cdot 10^{-2}$	$0.8 \cdot 10^{-2}$	$1.4 \cdot 10^{-2}$
12 mm / h (moderate)	$1.4 \cdot 10^{-3}$	$1.4 \cdot 10^{-2}$	$3.7 \cdot 10^{-2}$	$7.1 \cdot 10^{-2}$
30 mm / h (strong)	$3.6 \cdot 10^{-3}$	$3.7 \cdot 10^{-2}$	$10.6 \cdot 10^{-2}$	$21 \cdot 10^{-2}$
70 mm / year (rain)	$8.7 \cdot 10^{-3}$	$9.1 \cdot 10^{-2}$	$28 \quad 10^{-2}$	$57 \cdot 10^{-2}$

From the table. 7 we can conclude that, for example, at a frequency of 3 GHz signal attenuation in the rain will be about 0.0087 dB/km, which on the route of 100 km will give 0.87 dB of total attenuation. As the operating frequency of the radio line increases, the attenuation of rain increases sharply. For the frequency of 4 GHz, the attenuation in the rain on the same route will be 9.1 dB, and at frequencies 5 and 6 GHz - 28 and 57 dB , respectively. However, it is assumed that rain with a given intensity occurs during the route, which is rare in practice. However, when using UAVs in areas where there is frequent high-intensity rain, it is recommended to choose the operating frequency of the radio line below 3 GHz.

3 Conclusions

Thus, it can be argued that mass-produced UAVs have a limited range of use in the SES, precisely due to the limited range of video communication, which is for common models up to 15 km within line of sight. The presence of interference due to terrain, vegetation, building density, weather conditions and sources of electromagnetic radiation will significantly reduce the range of video communication in real time. Therefore, this presupposes the use of such UAVs only for the tasks of spot video surveillance or other work with short range. It is possible to increase the range of video communication due to the existing individual systems that have the necessary technical characteristics. However, the use of such systems with mass-produced UAVs is almost impossible for the vast majority of models. The way to universalize the UAV fleet is to develop and create a unified UAV based on existing technical solutions for the needs of the SES.

4 Prospects for Further Research

The ideal variant of a unified UAV for the needs of the SES is to use a model with maximum range, significant traction of the aircraft, a powerful video transmitter using modern methods of encoding / decoding video data and equipping the ground control station with equipment for receiving/transmitting data.

The cost of such serial models is quite significant. Therefore, the best option is to create such devices on the basis of existing individual technical solutions. However, given the requirements of the current regulatory framework for state-owned aircraft, the main difficulty is the issue of registration of such aircraft.

References

[1] O. Tyshchenko, I. Maladyka, A. Bychenko, M. Pustovit. Possibilities of UAVs of different types during the performance of assigned tasks in the field of SES. Theory and practice of firefighting and emergency response: Proceedings of the XII International Scientific and Practical Conference. Cherkasy: ChIFS named after Chernobyl Heroes NUCD of Ukraine, (2021) 133-135.

[2] Orel B., Pustovit M., Orlov S. System transmission data on large distance for unmanned flying apparatus. Materials of the All-Ukrainian scientific and practical conference of cadets and students "Science of Civil Defense as a way of becoming young scientists" conference. Cherkasy: ChIFS named after Chernobyl Heroes NUCD of Ukraine, (2021) 175-177.

[3] On approval of the Rules of registration of state aircraft of Ukraine and the Rules of certification of a copy of the state aircraft of Ukraine: order of the Ministry of Defense of Ukraine of 07.02.2012 № 63 (as amended). "Legislation of Ukraine", Verkhovna Rada of Ukraine. URL: https://zakon.rada.gov.ua/laws/show/z0334-12#Text (access date 12.01.2022).

[4] On admission to the operation of unmanned aerial vehicles: order of the SES dated 20.11.2018 № 675. URL: https://www.dsns.gov.ua/ua/Nakazi/85780.html (application date: 12.01.2022).

[5] On amendments to the order of the SES dated 20.11.2018 № 675: order of the SES dated 08.02.2019 №92. URL: https://www.dsns.gov.ua/ua/Nakazi/89229.html (access date: 12.01.2022)

[6] C.A. Balanis. Antenna theory. Analysis and design. Fourth edition. John Wiley & Sons. 2016

[7] Boev N.M. Command and telemetry analysis radio lines communications with drones flying devices. Siberian aerospace magazine. 2 (42) (2012). URL: https://cyberleninka.ru/article/n/analiz-komandno-telemetricheskoy-radiolinii-svyazi-s-bespilotnymi-letatelnymi-apparatami (access date: 12.01.2022).

[8] Antenna gain. URL: https://en.wikipedia.org/wiki/Antenna_gain (accessed 12 January 2022).

[9] Kalinin A.I., Cherenkova E.L. Spread radio waves and work radio lines. Communication. Moscow, 1971

Advances in Science and Technology
ISSN: 1662-0356, Vol. 114, pp 41-49
doi:10.4028/p-i5mfl9

Submitted: 2022-04-14
Accepted: 2022-04-28
Online: 2022-07-29

Remote Visual Information System for Identification of Dangerous Substances Using Unmanned Aircrafts

Bychenko Artem[1,a*], UDOVENKO Maksym[1,b], NUIANZIN Vitalii[1,c], BEREZOVSKYI Andriy[1,d]

[1]Cherkasy Institute of Fire Safety named after Chornobyl Heroes of National University of Civil Defense of Ukraine, Onoprienko 8 str., Cherkassy, Ukraine, 18034

[a]artem_b2003@ukr.net, [b]max.udovenko@gmail.com, [c]Nuyanzin@gmail.com, [d]andrey82-07@ukr.net

Keywords: unmanned aerial vehicle, hazardous chemical, remote identification, software, information technology, civil protection.

Abstract. Development of a functional model of the process of creating a knowledge base on the recognition of objects and actions of the enemy on the basis of neural networks and fuzzy logic. The aim of the work is to develop a set of software and hardware designed for remote identification of hazardous substances by machine visual recognition of information signs of dangerous goods with the output of relevant information to the means of visual display (interface). Recommendations concerning providing UAVs with the necessary technical means to monitor the zone of emergencies are analyzed. The recommendations of the organization of radio communication between the UAV and the operator depending on the range of the UAV departure, terrain conditions etc are analyzed and given. The structural scheme of the complex of remote recognition of HC in the form of blocks, units and software and hardware is developed. As a result of the analysis of programming systems, it was found that Python programming language is the best choice to ensure the full operation of the software due to the built-in capabilities and the involvement of third-party frameworks. A database containing information on more than 3.000 HCs with detailed recommendations for emergency response is developed. The hardware and software complex for remote identification of dangerous substances by machine visual recognition of information signs of dangerous goods by UAV, consisting of unmanned aerial platform with photo-video recording means, data transmission system to ground control station, PC for processing results and related software are substantiated and developed. A test of the UAV's capabilities in recognizing danger signs with UN numbers in different lighting conditions was tested. In all cases, the HC was accurately identified. The ideas and methods proposed in this article will allow to create cheap and simple tools for rescue units of Ukraine, which deal with the consequences of emergencies related to the leakage of HCs.

Introduction

The issue of civil security has always been one of the main issues for Ukraine, and in the conditions of aggression on the part of the Russian Federation it has played a key role. The destruction of the bombings affected a large number of places for storage of hazardous chemicals (hereinafter – HC), highways along which they move, temporary tanks and more. The work of the units of the SES of Ukraine on liquidation of emergencies, which are related to the circulation of the HC begins with a detailed reconnaissance of the scene. Reconnaissance is primarily about identifying HC, and this is a difficult task in the context of hostilities, as there is not always information on what substance leak needs to be eliminated, despite the fact that the situation at the scene may pose a threat to rescuers. Therefore, the identification of HC should be carried out at a safe distance, analyzing the special signs that inform about the dangerous substance that is in the tank.

For remote identification of the HC, it is advisable to use unmanned aerial vehicles (hereinafter – UAVs), which are in the service of SES of Ukraine.

UAVs have a number of advantages that make them indispensable for such tasks, namely, have a relatively low cost, availability and the ability to quickly master the skills of piloting UAVs by operators. Ways to use UAVs in emergency response areas require careful planning, starting from traffic routes, locations of operators, obstacles on traffic trajectories, formation of control decisions, etc.

This can be achieved by creating an intelligent decision support system (hereinafter – DSS) [1, 2]. Implementation of information technology for UAV flight route planning within the framework of DSS will allow to form the architecture of a promising intelligent decision support system for UAV action planning.

Analysis of Literature Data and Problem Statement

There are many ways to mark [3] HC in the world, but the most common in Europe and Ukraine is to mark HC with UN numbers.

The UN number is a numerical designation of the HC, which is determined by UN recommendations. It means that each HC has its own UN number.

To simplify the procedure for identifying the HC, unified rules for marking and transportation of HC by different modes of transport have been developed by UN (Fig. 1).

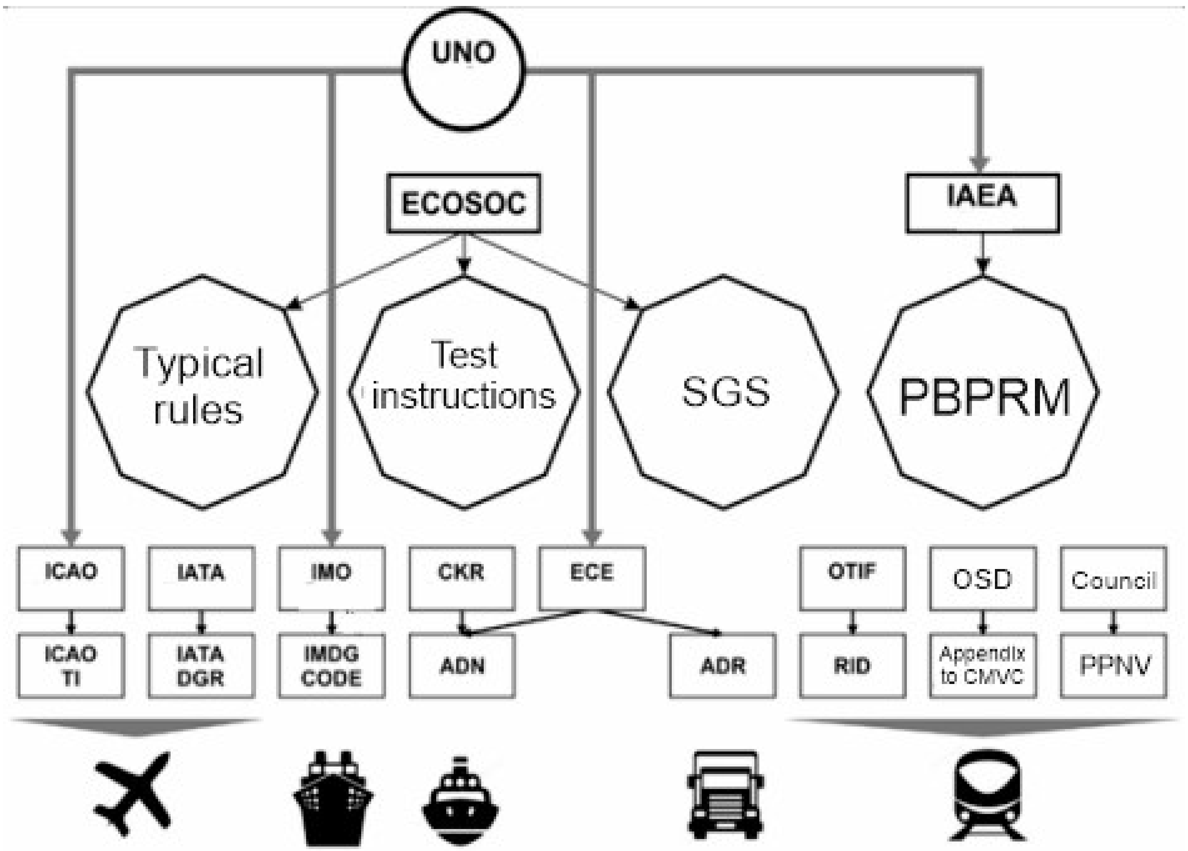


Fig. 1. Basic conventions and agreements governing the transportation of dangerous goods by various modes of transport

According to the recommendations developed by the UN, each dangerous goods transported by road or rail is equipped with an orange danger sign [4] (Fig. 2). The symbols on the warning plate are divided into two parts, which contain information about the danger of the cargo: the number of danger (upper field) and the UN number (lower field).

Fig. 2. Warning table for dangerous goods

The study of UAVs was started in the last century for military purposes, today UAVs are widely used in various areas of human life, including rescue units [5].

To date, the main efforts to use UAVs are aimed at studying the processes of automation of UAV route planning to find dynamic and stationary objects based on the use of systems analysis methodology, probability theory, mathematical modeling, elements of artificial intelligence, modern information technology. This leads to the need to develop information technology for automated planning of UAV actions during their mission using object-oriented design method within DSS. Many works have been devoted to the improvement of information technologies for these purposes [6–8].

It is clear that the issue of full automation of the process of identification of HC in the emergency is not possible today, but to begin its implementation today is an urgent task to improve the efficiency of SES units in dealing with emergencies with leakage of HC.

Purpose and Objectives of the Study

Development of a set of software and hardware designed for remote identification of hazardous substances by machine visual recognition of information signs of dangerous goods with the output of relevant information on the means of visual display (interface).

Software and hardware implementation of the above complex is possible if the following tasks are solved:

1. To identify the requirements for the hardware of the complex;
2. To develop a block diagram and algorithms of the software of the complex;
3. To determine the programming language;
4. To identify the necessary additional tools of the software complex;
5. To develop software for visual recognition of HC markings;
6. To verify the obtained research results.

Materials and Methods of Research

The following technical devices can be attributed to the hardware of the complex for remote identification of dangerous substances by machine visual recognition of information signs of dangerous goods:

- Unmanned aerial platform;
- Photo-video camera of the unmanned aerial vehicle;
- Data transmission system from the UAV to the ground control station;
- PC for the software part of the complex.

It should be noted that the unmanned aerial platform, in case of its use in places with possible leakage of HC, must be subject to special technical requirements aimed at the possibility of decontamination, both the platform as a whole and its individual technical components.

The main technical characteristics of photo-video cameras installed on UAVs for image recognition are resolution. Complicating conditions for the operation of visual aids can be considered weather conditions, the presence of aerosol or vapors of HC at the observation site, the angle of shooting, the presence of UAV vibrations that can lead to distortion of visual information etc. Therefore, it is clear that the resolution of the above means should be as high as possible, in accordance with modern technical capabilities. The photo-video camera of the unmanned aerial vehicle must be equipped with a stabilization system, have an appropriate level of protection against adverse environmental factors. The light-sensitive matrix of the photo-video camera of the unmanned aerial vehicle must provide the ability to work in low light conditions.

The most convenient way to obtain photo and video data is real-time observation, which involves the transmission of video signals in various formats over the air. The limitation of this method is the significant amount of information transmitted. This causes high demands on the systems of reception and transmission of such information and forces UAV manufacturers to make technical and economic compromises. Real-time video broadcast from the UAV is conducted to the ground control station, usually in the ultra-shortwave or ultra-high frequency range, which is characterized by the location of the aircraft in the "line of sight" of radio waves in space. The maximum range of video transmission depends on the specific characteristics of the UAV systems used, for example, at frequencies of 2.4 GHz, it is about 10–15 km. The presence of interference due to terrain, vegetation, building density, weather conditions and sources of electromagnetic radiation will significantly reduce the distance of video communication in real time. In view of the above, the main requirements for UAV data transmission systems to the ground control station are the maximum bandwidth of the communication channel, high power of the photo-video data transmission system, high-quality matching of antenna devices and sufficient power of the transceiver processors..

The use of image recognition technologies by machine learning requires significant computing power, which is determined by the clock rate and number of processor cores, the amount of RAM and the power of the video information processing system. Thus, it will be optimal to use a PC with maximum characteristics [9–11].

The block diagram of the complex in general can be represented as a set of blocks, nodes and software and hardware (Fig. 3).

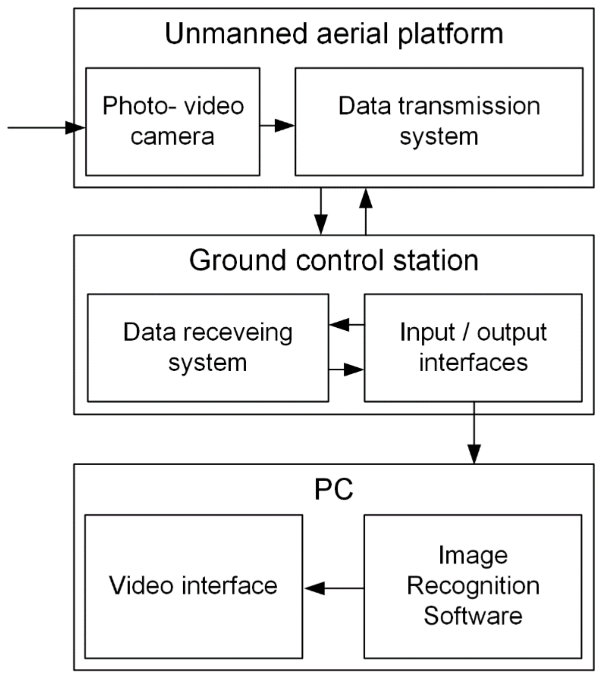


Fig. 3. Block diagram of the complex

The algorithm of the recognition system in general can be represented as follows:

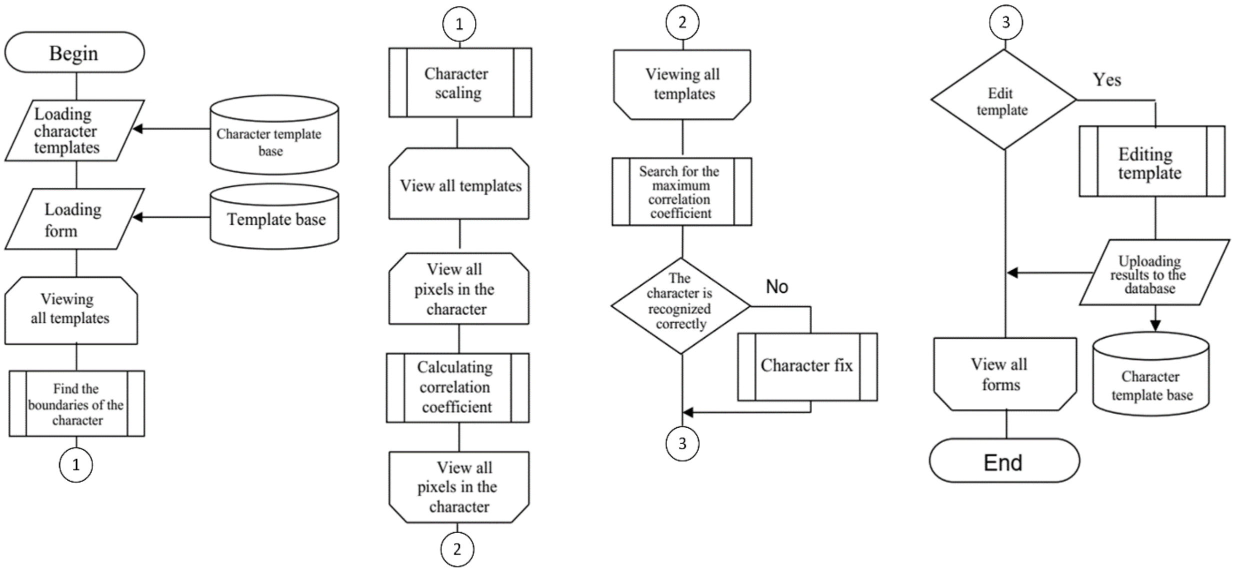


Fig. 4. The algorithm of the recognition system

As a result of the analysis of programming systems [6], it was found that programming language Python is the best choice to ensure the full operation of the software due to the built-in capabilities and the involvement of third-party frameworks. The key differences of this language are fully automatic memory management, the connection of types with objects rather than variables and a high level of abstraction when performing operations. The availability and relative ease of implementing projects with Python make it one of the leaders in high-level programming languages.

Pattern recognition technology is a fairly advanced technology at this stage, so to solve our problems it is advisable to use ready-made common software solutions.

One of them is Tesseract, an open source software that allows you to recognize characters with support for Unicode encoding and the ability to recognize more than 130 languages. This tool is open and free, as well as suitable for creating cross-platform software that can be used on computers with different operating systems.

OpenCV (Open Source Computer Vision Library) is an open source library for working with computer vision algorithms, machine learning and image processing. OpenCV element recognition uses object outlines, color segmentation, and built-in recognition methods that can be customized depending on the object and the sensitivity of the algorithm. OpenCV includes more than 2.500 tools and algorithms for computer vision and machine learning. Thanks to its high speed and cross-platform nature, OpenCV is suitable for working with real-time images.

In general, the following procedure is provided - when the operator receives an image from a UAV, which is in a dangerous environment, the software recognizes the text and automatically searches the database (Fig. 5). The database, which contains information on more than 3.000 HCs with detailed recommendations on emergency response, was developed by our team as part of previous research commissioned by SES of Ukraine [3].

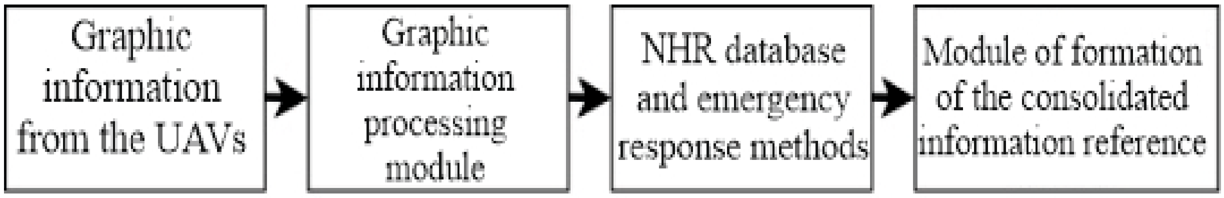


Fig. 5. Schematic diagram of the information system of action planning of unmanned aerial vehicle operators

Figure 6 shows the results of testing the software for recognizing the symbols depicted in the table of hazard. During the verification of the hardware and software complex, the influence of adverse weather conditions, lighting, etc; the effect of the presence of aerosols or vapors of HC at the observation site; the dependence of the number of successful recognitions on the shooting angle are checked.

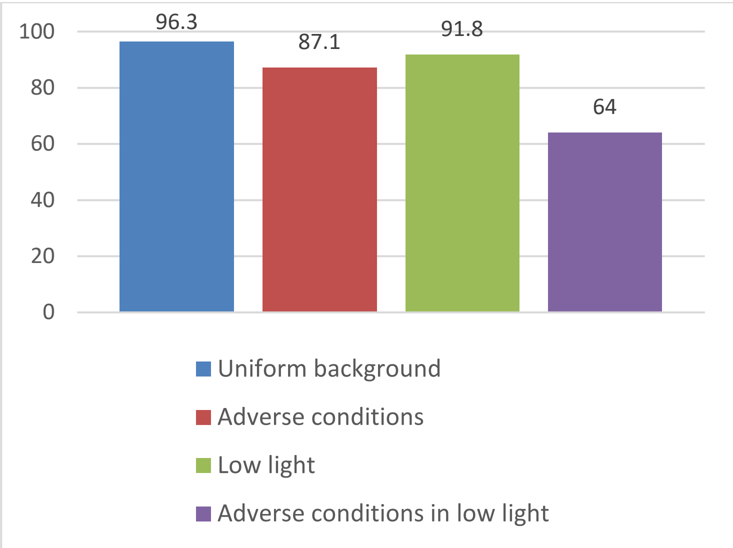
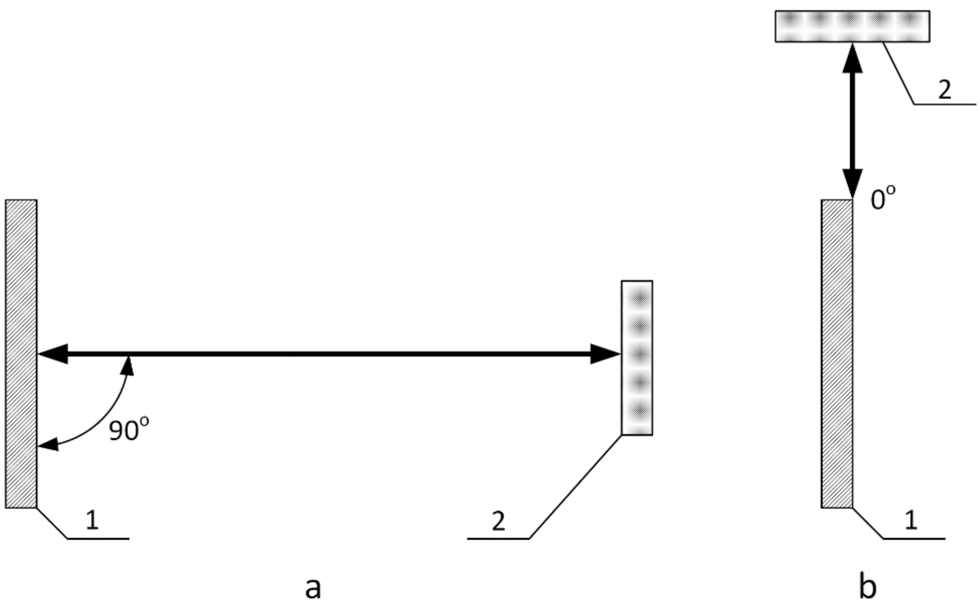


Fig. 6. Test results of character recognition software

The most ideal shooting option can be considered a situation where the movement of light rays from the shooting surface to the light-sensitive matrix of the camera will be carried out at an angle of 90 degrees (Fig. 7 a). The worst option that makes recognition impossible is the option when the movement of light rays from the shooting surface to the light-sensitive matrix of the camera will be at an angle of 0 degrees, which is not possible due to the location of the light-sensitive matrix to the shooting surface at an angle of 90 degrees. (Fig. 7 b)



1 – shooting surface; 2 – light-sensitive matrix

Fig. 7. Reciprocal location of the survey surface and the light-sensitive matrix

According to the results of research with a gradual decrease in the angle of observation from 90 degrees to 0 degrees with a step of 10 degrees, the dependence is obtained, as shown in the graph (Fig. 8).

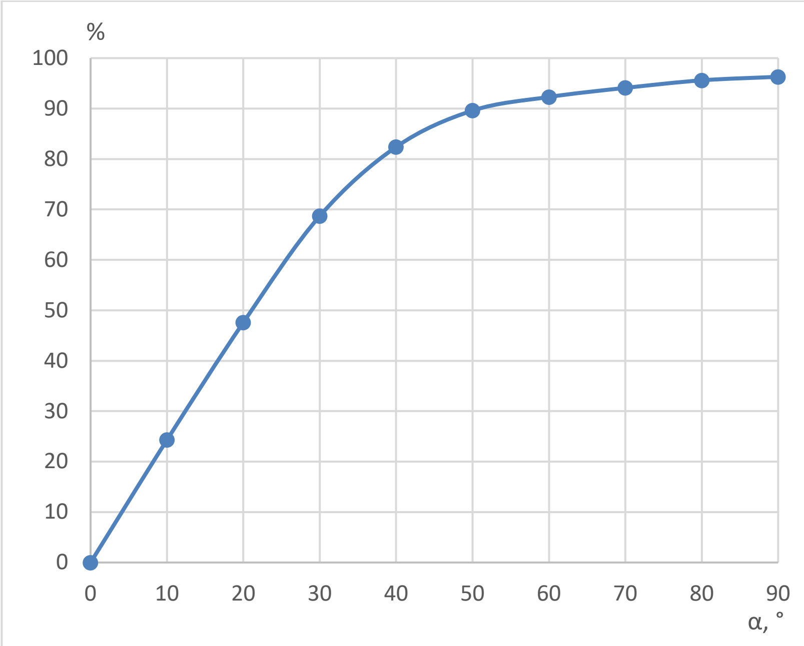


Fig. 8. Dependence of the probability of correct recognition of symbols on the angle of observation

The process of work of the developed software for remote visual information system for the identification of hazardous substances using unmanned aerial vehicles is shown in Fig. 9. As can be seen from the figure, the purpose of the work is achieved.

Fig. 9. General view of the research site with the use of the UAV

Discussion of Results

The technology of recognition of information signs of dangerous goods with the help of UAVs allows you to quickly determine the type of HC, which will optimize management decisions to eliminate the consequences of emergencies. The software and hardware complex implements the ability to automatically recognize the signs of dangerous goods with the help of UAVs during reconnaissance of emergencies with leakage (emission) of HC. Problematic issues of using UAVs for pattern recognition are adverse weather conditions, the presence of aerosol or vapors of HC at the observation site, the angle of shooting, the presence of UAV vibrations. The influence of the shooting angle, external conditions mentioned above, on the quality of image recognition is studied.

The next step in software development will be to adapt it to situations where the image is not clear. To work with such images, two methods of information processing will be used:

- automatic – when fuzzy image analysis methods are used, such as those described in [12];
- manual – when the operator will be able to query the database by entering the HC code from the image.

At this stage, the database of hazardous chemicals must be adapted for use with the image analysis module.

Prospects for further research are to add the ability to recognize graphic danger signs, text symbols on containers with HCs and reduce the impact of UAV vibrations on the quality of the resulting image.

Conclusions

The hardware-software complex for remote identification of dangerous substances by machine visual recognition of information signs of dangerous goods with the help of UAVs, consisting of unmanned aerial platform with photo-video recording means, data transmission system to ground control station, PC for processing results and corresponding software were substantiated and developed.

The ideas and methods proposed in this article will allow to create cheap and simple tools for rescue units of Ukraine, which deal with the consequences of emergencies related to the leakage of HCs.

References

[1] N.A. Koroliuk, S.N. Ieremenko, Intelligent Decision Support System for Controlling Unmanned Aerial Vehicles at the Ground Control Station, Systemy obrobky informatsyi. 8 (133) (2015) 31–36 [in Russian].

[2] A.S. Buryi, M.A. Shevkunov, Approach to the construction of decision support systems for the control of unmanned aerial vehicles, Transportnoe delo Rossii. 6 (2015) 22–26 [in Russian].

[3] A.O. Bychenko, V.M. Nuianzin, A.I. Berezovskyi, M.O. Pustovit, The problem of identifying hazardous substances in emergencies, Pozhezhna bezpeka. 14 (2013) 38–43 [in Ukrainian].

[4] Dangerous Cargo is. Marking: DSTU 4500-5:2005. – [Valid from 2005-12-28]. – Kyiv: Derzhstandart Ukraine [in Ukrainian].

[5] H.A. Leshchenko, Ya.S. Mandryk, V.M. Stratonov, S.A. Davydov, Methods of using unmanned aerial vehicles during air search and rescue, Naukoiemni tekhnolohii. № 3(51) (2021) 271–280. https://doi.org/10.18372/2310-5461.51.15998 [in Ukrainian].

[6] S.I. Matorin Analysis and modeling of business systems: systemological object-oriented technology. Kharkiv: KhNURE, 2002 [in Russian].

[7] A.I. Timochko, S.A. Olizarenko, O.Yu. Lavrov, A method for deciphering aerial photographs based on feature space, Systemy obrobky informatsyi. 1 (126) (2015) 84–87 [in Russian].

[8] S.A. Olizarenko, Development of a functional model of the process of creating a knowledge base on the recognition of objects and actions of the enemy on the basis of neural networks and fuzzy logic, Zbirnyk naukovykh prats Kharkivskoho natsionalnoho universytetu Povitrianykh Syl. 1 (50) (2017) 58–62 [in Ukrainian].

[9] A. Parra, B. Zhao, A. Haddad, M. Boutin and E. J. Delp, Hazardous material sign detection and recognition, 2013 IEEE International Conference on Image Processing. (2013) 2640–2644. DOI: 10.1109/ICIP.2013.6738544.

[10] A. Sharifi, A. Zibaei, M. Rezaei, A deep learning based hazardous materials (HAZMAT) sign detection robot with restricted computational resources, Machine Learning with Applications. 6 (2021) 100–104.

[11] W. Benesova, M. Kottman, O. Sidla, Hazardous sign detection for safety applications in traffic monitoring, Proc. SPIE 8301, Intelligent Robots and Computer Vision XXIX: Algorithms and Techniques, 830109 (23 January 2012). https://doi.org/10.1117/12.905813.

[12] O. Nuianzin, O. Kulitsa, M. Pustovit, M. Udovenko, Method of Increasing the Availability of Video Information of Aerial Monitoring in the Airspace of a City. Volume 59: Modern Technologies Enabling Safe and Secure UAV Operation in Urban Airspace. DOI: 10.3233/NICSP210009.

Keyword Index

Author Index