The formulation and solution of the problem of constructing optimal trajectory as a means of eliminating socio-legal contradictions in the realization of unmanned robotic systems

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Abstract

The problems of introducing mobile robotics for ground and air use to meet the growing needs of society are considered. It is determined that existing legislative contradictions are the main obstacle to the introduction of air vehicles into domestic delivery services. The complex application of unmanned technologies is proposed. To eliminate contradictions and determine the optimal parameters of their application, the structure of an automated system is presented. A mathematical model of efficiency assessment is proposed, which allows determining the optimal parameters of the application of unmanned technologies for ground and air operation in combination with developed services and eliminating legislative contradictions. Computer modeling was carried out and data was obtained that confirm the feasibility and effectiveness of the complex application of unmanned technologies.

Keywords

automated systems, unmanned technologies, legislative contradictions, efficiency assessment, modeling

1. Introduction

Reducing labor intensity and total costs through the introduction of automation is one of the urgent tasks of modernization not only of production enterprises, but also of service and service areas in the everyday life of citizens. In this regard, the task of automation and robotization of life processes, as a tool for increasing the productivity of society, becomes a priority. Its solution requires increasing efficiency, including for the non-productive sphere. One of the ways to ensure the efficiency of such technological processes in the everyday life of a family, village, city is to improve communication and service systems. The needs of citizens related to everyday life and the means of satisfying them are improved through innovative developments and automation of their organization, support and implementation as automated control systems (ACS). The successes demonstrated in the field of development of unmanned technologies, namely mobile robotics for ground and air use and the growing need for them in society stimulate the search for technical on the roads are analogues of autonomous route planning and navigation in transport systems. Examples of developments: Waymo, Tesla Autopilot, Uber ATG, Baidu Apollo, Mobileye - as examples of implementation are

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included in everyday life. The twelve years have passed since the first publication by Amazon CEO Jeff Bezos of his idea to deliver packages to customers using unmanned aerial vehicles (UAVs). Now it does not matter who immediately asked how such a bold proposal could work at all. The reason for this was the contradictions with the legislation on flights over private property and on the space closed to flights in the city. However, even today, when aerial drones practically demonstrate their then unexpected capabilities, contradictions of this type are even more acute. The set of innovative solutions protected by patents of various companies and authors does not provide an answer to this challenge of scientific and technological progress. The system of technological operations of the delivery company, as the final structure entering the market, is inhibited, since the system of technical and legislative solutions has become an unpredictable main challenge [4]. Of course, the technology of using UAVs in everyday life will depend on a number of legislative acts, factors of external influence of private and other types of property and the arrangement of relations and technologies that are not suitable to be described and regulated by patents [5]. Thus, the program of movement of unmanned aerial vehicles, which covers a large territory, will depend on the air traffic control system of vehicles, the task of which is to effectively and safely coordinate the work of autonomous unmanned aerial vehicles in the airspace. In this regard, the tasks of creating ASCs that implement the use of UAVs in everyday life become tasks of further spreading scientific and technological progress in the sphere of domestic use of aerial drones [6].

2. Analysis of recent publications

One of the common representatives of the implementation of unmanned technologies is the UAV [7]. These include remotely controlled aircraft, flying autonomously, without an operator on board. However, despite the progressiveness of the proposals for a new form of motion description, they will not ensure the elimination of legislative contradictions when operating UAVs in the city [7].

The second approach to the control of unmanned technologies of the neural network, using matrix hyperbasis functions, is proposed in [8]. The processing of non-traditional vector information is solved here by introducing a matrix hyperbasis function using a recurrent online algorithm for its training. These actions simplify the architecture by eliminating autoencoders and adjusting synaptic weights and parameters of the hyperbasis activation functions. However, this approach [8] creates new problems in the control of unmanned technologies, which are caused by the simultaneous presence of quantitative and qualitative components of vectors and the need to find weight coefficients during training and rapid change of norms. Important for further development is the work [9], which analyzes trends and challenges of AI for various areas of application, discusses the structure of computerized systems with elements of artificial intelligence (AI) and the methodology of design and 3D modeling, including IR and MRTS movements. Further advancement of its results with simultaneous application of special filters generates innovative solutions [9]. Their important informational supplement, provided by the system of sensor modules, generates new information flows [10]. Their combined information completeness determines the majority of events and conditions, which expands the possibilities for analysis and synthesis of control influences [10]. Further development and examples of implementation of machine learning methods to increase the efficiency of robot sensors and control information is provided by the robot [11]. An analysis of processes and learning tools to increase the efficiency of functioning is presented robot sensors and information field that expands and complements existing control algorithms [11].

An example of an innovative application of the machine learning method to systems implementing unmanned technologies is proposed in the work [12]. It investigates the features of early diagnosis of the state of functioning of nodes in unmanned technologies through predictive maintenance of wind turbine bearings: the MLOps approach with the DIAFS machine learning model is predictive maintenance for wind turbine bearings: An MLOps Approach with the DIAFS Machine Learning Model [12]. Its further spread as a structural element of unmanned technologies becomes an obvious need for their development [12]. Work [13] considers trends and challenges of development and implementation of artificial intelligence in the processes of intelligent data collection of advanced computing systems and determines the prospects of technologies with their application. An example of the spread of the idea of accurate prediction of the potential for damage to buildings at the design stage is work [14]. It offers estimates of vital factors affecting the mitigation of impacts on neighboring infrastructure and determines safe development practices. By building fast and effective predictive models for assessment and use of machine learning (ML) tools using a dataset and eight local and global indicators important for modeling damage and their predictive estimates [14].

The development of artificial intelligence tools and examples of generalized estimates in the form of a vector indicator as such are demonstrated in the work [15]. Their effectiveness and applicability for the description and analytical solution of problems of kinematics and dynamics of mobile robotic systems and error estimation is useful in the creation of their decision support systems [15]. Design, using simulation modeling, provided to the developer using software environments such as MathCad, MATLAB and SolidWorks on the example of an automated line for cutting slots of ring blanks is presented in the work [16]. Optimization of parameters and complex application of modern environments also offers examples of constructive solutions of robotic production systems with certain parameters of efficiency and reliability in industrial conditions [16]. In this regard, the work [17], which demonstrates practical experience of unmanned technologies based on the joint operation of UAVs and IoT as a multi-version monitoring system after large-scale accidents. Structural elements, their consistency in operation and reliability during monitoring provide experience in the construction and joint operation of IoT and human-machine automated production [17]. An important and attractive is the innovative proposal for the joint use of cobots, which is put forward in the work [18]. The area of complex use of cobots, industrial robots and unmanned vehicles opens up new boundless prospects, which are currently not possible to fully determine [18]. Thus, the works described in the review [7-17] are attractive for the design and improvement of UAV systems, but they do not resolve the contradictions that prevent their implementation in everyday services. In this regard, the main unsolved problem is to eliminate the contradictions for the use of UAVs in everyday life. The work aims to study and propose a set of actions for the implementation of UAVs in everyday life based on an AI assessment tool such as effectiveness.

3. Purpose and objectives of the study

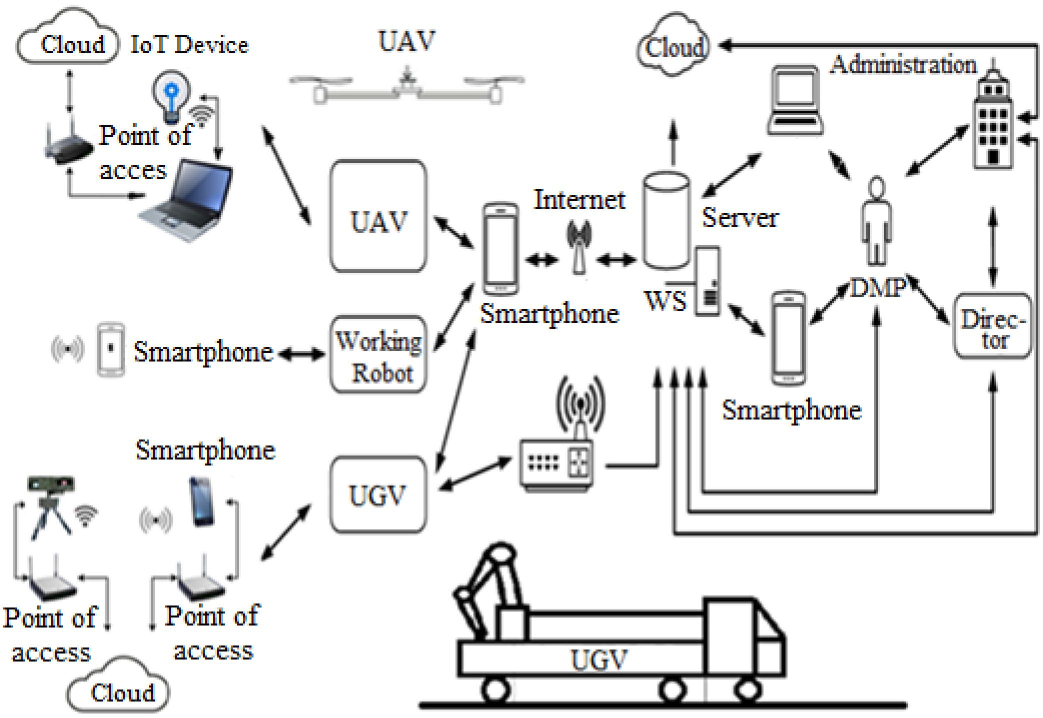
The aim of the study is to increase the efficiency of UAV use in everyday services through the integrated use of unmanned technologies and existing service structures, which will eliminate legal contradictions and optimize parameters based on a comparison of efficiency indicators. To achieve this goal, the following tasks were formulated

- develop a concept for the structure of a functional diagram automated process control system when using UAVs and unmanned technologies and services in everyday life;
- to propose a generalized indicator for calculating the efficiency of a technological process consisting of several types of unmanned technologies and services in everyday life;
- to conduct modeling and demonstrate, based on a comparison of alternatives, the reality of the comprehensive application of unmanned technologies for the performance of services and the organization of new services in everyday life without legal violations and objections.

4. The concept of building a functional diagram ACS as a technological process with unmanned technologies

4.1. Hypotheses, ideas, concept, functional diagram ACS as a technological process when using UAVs

The Amazon idea was reviewed and, based on the analysis, a new concept for the structure of services and the use of UAVs in everyday life was formulated.
Firstly, it was based on a functional solution to supplement the already developed delivery service with the latest elements of the UAV service.
Secondly, the path reduction should be carried out strictly by selecting movements in the directions of permitted unmanned flights and planning unmanned ground movements by electric cars, which provides the opportunity to flexibly eliminate legal obstacles. A graphical representation of the functional diagram demonstrating the new concept is presented in Fig. 1.



Fig

Figure 1: Functional diagram of the ACS TP for the use of UAVs in everyday life

Thirdly, the use of the existing network of service centers distributed throughout the service provision area ensures their effective information communication. Thanks to radio communication channels Bluetooth and Wi-Fi and other wireless networks and with the help of cloud services including IoT, two-way information exchange is ensured. In addition to service centers, automated loading areas for UAVs, robots, and auto UMCARs were introduced, which load delivery vehicles according to the optimal types of deliveries. It was also envisaged that consumers as potential customers are also united through an application installed on a smartphone (Android). All participants in the unmanned ACS TP of everyday life are monitored and their operational progress is recorded and stored on the server. The decision-maker (DM) is provided with information support through the interface and intervenes in the process if necessary. The administration also manages the process and monitors the status of the system and the equipment fleet with the help of technical, engineering services and repair specialists (they are not shown in the figure).

Such a functional scheme Fig. 1, which represents the functional elements of the unmanned ACS TP of everyday life in graphic images, is detailed by a block diagram that displays the connections between the functional blocks. These functions, which are reflected by inputs, outputs, control influences and disturbances, will be denoted by the vectors **X, Y, U, W,** respectively. We will also introduce lower and upper indices and conditionally assume that the lower one denotes the block from which the value came, and the upper one to which it is supplied. So, for example, if it is necessary to provide coordinates relative to the base coordinate system and the angles of orientation of the device in the initial position, which is given by the output vector from the first block $\overline{Y}_1$ then we will write:

$$\overline{Y}_1 = [X_1, Y_1, Z_1, \theta_1, \varphi_1, \psi_1]^T$$

From this example it is clear that this is the output signal from the first block. However, to formulate and solve the problem of constructing optimal solutions, it is also necessary to specify the value $\overline{Y}_2$ position vector and orientation of the device in final position 2:

$$\overline{Y}_2 = [X_2, Y_2, Z\ , \theta_2, \varphi_2, \psi_2]^T$$

To eliminate such interpretation problems, we will introduce double indexing for superscripts and subscripts.

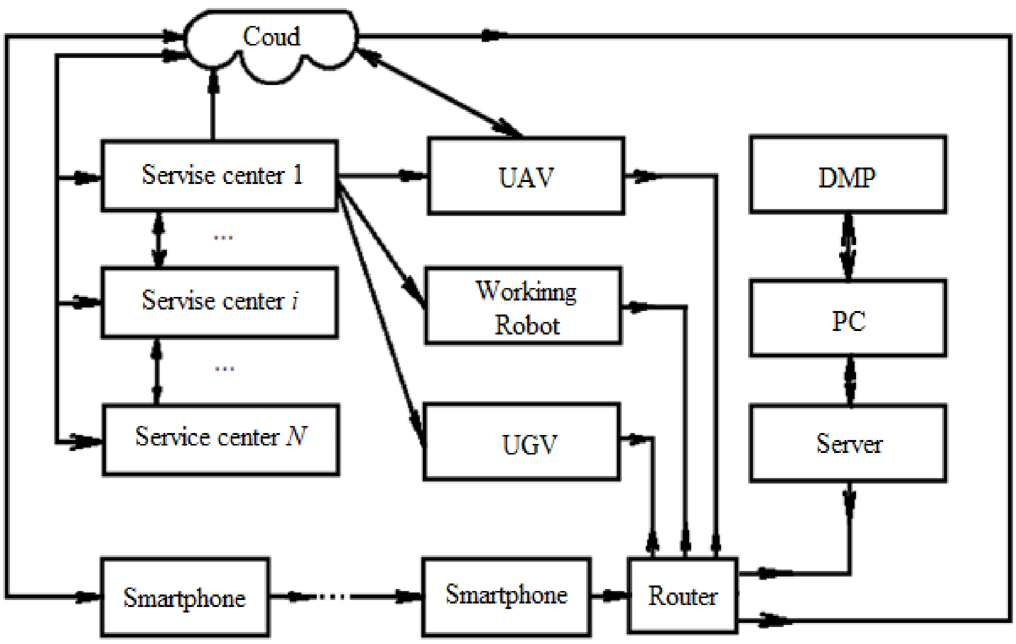


Figure 2: Block diagram of the ACS TP for the use of UAVs in everyday life

A graphical representation of the block diagram demonstrating the new concept is presented in Fig. 2. An alphanumeric symbol has been introduced for its formation, which in the future will simplify the work of the operator and the decision-maker (DM) and the interpretation of the ACS states according to the interface that will need to be created.

The main defining structural elements are N service centers, which are created separately or existing centers of automated services are used, which are additionally adapted to work with ACS TP of everyday life. These centers are information-connected with wireless networks and are serviced by cloud services, including through applications of "Android" smartphones and routers by means of two-way exchanges. The outputs from the service centers are fed to the inputs of the corresponding automated sections of loading UAVs, BP work, BPE cars in accordance with the tasks and information additions from the DM, cloud networks, server and the state of the site.

The presented block diagram conditionally does not reflect towers, radio communication antennas and the wired Internet network, since their functional role in the operation of the ACS TP of household services at this stage is not significant.

According to the algorithm of functioning of the ACS TP of everyday life of the PC based on orders received via wireless networks and smartphones. Additionally, information is added about the order and the workload and the progress of the execution of orders by each of the types of sites and an unmanned aerial or ground-based drone or a robot that controls the execution of services. Thus, the functional diagram of Fig. 2 is, together with the introduced system of definitions, the basis of the conceptual model.

4.2. The effectiveness of the ACS TP application of UAVs in everyday life and the need for spatial modeling of its movement

Today, when aerial drones and unmanned technologies demonstrate their unexpected capabilities in practice at the first presentation, the legal basis for the operation of drones as aerial vehicles is even more acute. The set of innovative solutions protected by patents of various companies and authors does not resolve legal contradictions, which slows down the advancement of scientific and technological progress. The system of technological operations of the company's delivery, as a structure suitable for entering the market, requires, along with structural additions, the development of means of assessing the state and supporting decision-making. Yes, the drone movement program, which covers a large area, will depend on the air and ground traffic control system of vehicles and the ability to effectively and safely coordinate the operation of the system of autonomous unmanned vehicles. In this regard, the tasks of creating an ACS and DSS of a hybrid type are becoming the main tasks of further spreading scientific and technological progress in the sphere of domestic use of unmanned technologies. One of the common representatives of the implementation of unmanned technologies is UAVs. These include aircraft that are remotely controlled, fly autonomously, without an operator on board. However, in order to further eliminate the problems of legislative contradictions of the operation of UAVs over the city, it was set to expand the ACS by supplementing it with the technology of using unmanned ground robots of carriers and performers of loading and unloading operations. In addition, it was taken into account that the system is supplemented with points of reception and issuance of objects of transportation and automatic selection and storage. For example, as is done in supermarkets, pharmacies and other institutions that provide delivery services. For detailed modeling of such systems, the influence of various factors on the efficiency of operations and the overall efficiency of the service provision node was investigated. The overall efficiency of a technological process E_o with required result A_o and the probability of its successful execution P_o for the total time of operation T_o, including summarized expenses of the i-th C_{oi}, for N types of services, taking into account this notation, can be determined:

$$E_o = A_o P_o \left(T_o \sum_{i=1}^{N} C_{oi} \right)^{-1} \tag{1}$$

Calculating the overall efficiency of a technological process E_o is always complicated by problems of dividing it into N services or operations and calculating the efficiency of each of them. However, if these efficiency E_i and result of technological operation A_i and the probability of an execution of operation P_i for total time of operation – T_i of each $i - th$ operation are known, then we simply calculate the overall efficiency.

$$E_o = \frac{A_o P_o}{T_o} \left(\sum_{i=1}^{N} \frac{A_i P_i}{T_i E_i} \right)^{-1} . \tag{2}$$

The above demonstrates that the values of general indicators are not always known, so it is easier to make an assessment based on absolute indicators. In this regard, a model of the operation was developed. Let us denote m - the mass of the cargo that needs to be transported from the location point to the point of delivery to the consumer. There is also a flight from the point of location of the device to the location of the cargo, as well as a flight from the point of delivery to the consumer to the parking point of the device. Let`s notice ρ - density of air and S - square of the full surface, C_x - coefficient of resistance as a function of angle of attack, r - outside radius of the propeller of the drives, n - frequency of rotation shaft of the driver, and lower indexes show a number of the driver. Under these conditions, with a known trim angle ψ. The total work A_o can be estimated approximately for four engines, for example, of a quadcopter, as a result of the motion in the field of Earth's gravity and calculated taking into account losses as a result of work against forces of resistance, such as friction of surface and resistance of form:

$$
\begin{aligned}
A_o &= (x_2 - x_1)\begin{bmatrix} 2\left(\frac{1}{2}\rho S C_x n_1^2 r_1^2\right) + \\ +2\left(\frac{1}{2}\rho S C_x n_3^2 r_3^2\right) \end{bmatrix}\cos\psi + (y_2 - y_1)\begin{bmatrix} 2\left(\frac{1}{2}\rho S C_x n_1^2 r_1^2\right) + \\ +2\left(\frac{1}{2}\rho S C_x n_3^2 r_3^2\right) \end{bmatrix}\sin\psi = \\
&= 2\rho S C_x r_1^2\left(n_1^2 + n_3^2\right)\left[(x_2 - x_1)\cos\psi + (y_2 - y_1)\sin\psi\right]
\end{aligned}
\tag{3}
$$

The total cost C, as the sum of all expenses for this operation, will be obtained:

$$C = C_e + C_{dep} + C_{вp} \tag{4}$$

Electricity costs C_e determine by value V_e, is spent on charging the battery:

$$C_e = V_e\left(\frac{I_d U_d t_d}{\eta_d} + I_{eq} U_{eq} t_{eq} + I_l U_l t_l\right), \tag{5}$$

where I, U, t, η - are noticed correspondingly as current, drop of voltage, time, coefficient of useful action with indexes d, eq, l - are noticed as driver, functional equipment, and lighting.

Depreciation deductions for all equipment used:

$$C_{dep} = \mu_i V_i \sum_{i=1}^{N} \frac{T_{oci} + T_{stb}}{T}. \tag{6}$$

Where μ_i - depreciation rate for the i - th equipment, V_i - the initial cost from book value of the equipment, T_{oci} - sum of time to perform the operation in during of technological process, T_{stb}- sum of storage time between two technological operations in during of technological process, T - total operating time between two major repairs or scheduled replacement.

Expenses for direct wages for work performers C_w are calculated as salary executers or workers who control the movement of unmanned vehicles P_i multiplied by time expenditure T_i and salary for technicians and administrative persons P_{ati} multiplied by time expenditure T_{ati}, including ν taxes and payroll deductions:

$$C_w = (1+\nu)\sum_{i=1}^{N}\left(P_i T_{oci} + P_{ati} T_{ati}\right). \tag{7}$$

The total operation time is denoted by T_o, then to calculate the efficiency it remains to find the probability of delivering the cargo from point 1 to point 2 in a given time T_o

The problem can be solved through experimental tests or theoretically, by calculating the probability of a random variable falling into the interval:

$$[T_o - \Delta T, T_o + \Delta T]; \tag{8}$$

$$P = \int_{T_{\text{заг}}-\Delta T}^{T_{\text{заг}}+\Delta T} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\tau - m)^2}{2\sigma^2}} d\tau, \tag{9}$$

m– mathematical expectation of the operation execution time, σ – root mean square error, ΔT – estimate of the discrepancy of the operation execution time according to the speed deviation data. The specified value should be described as follows:

$$T_o = \frac{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}}{v_{aver}}; \tag{10}$$

$$\Delta T = \frac{1}{2}\left[\frac{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}}{v_{\min}} - \frac{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}}{v_{max}}\right]. \tag{11}$$

The distribution law is assumed to be normal, since several equally significant random factors such as wind, weather conditions, load, equipment readiness, etc. operate. The proposed model is flexible and suitable for express and accurate calculations during the simulation of work and calculation of the overall efficiency of the technological process consisting of N types of services. To ensure the operation of the nodes, there is a need to use special controllers and single-board computers suitable for long-term uninterrupted operation as part of the ASC of household services using unmanned technologies and drones. In addition, they must be socially accessible, have extensive program libraries and open-source software, which microcomputers have recently demonstrated Weidmüller, Jetson Nano, Arduino and others.

5. Modeling the comprehensive application of unmanned technologies for the provision of services and the organization of new services in everyday life without legal violations and objections

To simulate the operation of household drones as part of combined delivery services of different ranges, we will consider a section of the city, which is schematically shown in Fig. 3.

In Fig. 3, the boundaries of the highway are shown in black thick lines, and the boundaries

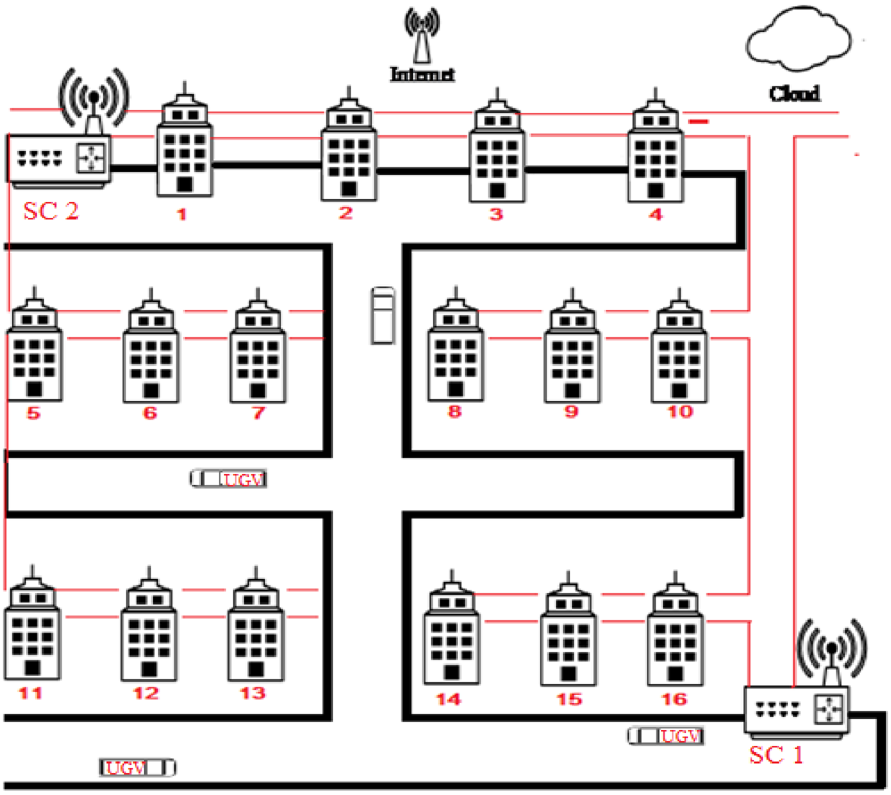


Figure 3: Generalized structural diagram of the city's microdistrict and comprehensive service points

of the zone permitted for UAV movement are shown in red thin lines. The PPV designations with numbers 1, 2, and so on indicate the points of receipt and delivery of shipment objects. The AB designation with serial numbers indicates unmanned vehicles capable of transporting shipment objects. The coordinates of buildings and delivery points are conventionally indicated by numbers, which will further determine the coordinates of these points with subscripts. It is assumed that all buildings, points of receipt and delivery of shipment objects, autonomous unmanned complexes work with unmanned complexes via cloud services, wired and wireless networks, and consumers' smartphones.

For modeling, we will choose an example of delivering an object weighing 30 kg to a consumer, the consumer is located in building 1 on the 27 th floor, the floor height is 3.5 m. Delivery must be made from the first floor of the building. Let us denote the initial coordinates of the cargo: X1=0, Y1=0, Z1=1 m. Customer coordinates: X2=-500 m, Y2=2500, Z2= 92.0 m. The simulation results are summarized in Table 1.

Table 1.

Results of simulation modeling of operations using a combination of unmanned technologies

No.	Method or type	Cost 1km of movement repair, UAH	Total costs C, UAH	Operation execution time T, hours	End point X,Y,Z, m	Probability of execution, intended/ actual
1	Autodrone	60	180	0.075	-500, 2500.1	1/0
2	UAV	45	135	0.083	-500, 2500.1	1/0

3	Robot	360	1080	0.5	-500, 2500.1	1
4	Car drone	60	180	0.075	-500, 2500.1	1
5	UAV	45	4,725	0.0029	-500, 2500,105	1
6	Robot	360	33.12	0, 1	-500, 2500,92	1
7	In the complex according to clauses 4,5,6.		217.37	0.1729	-500, 2500,92	1

In the initial simulation, horizontal movement was selected. The modeling process was performed taking into account the permitted routes. The movement of the autodrone was carried out only on the road, the movement of the UAV only in the permitted red zone, the movement of the robot only on the road. Analysis of the data in Table 1 for the first three options showed that the autodrone is not fully loaded for such conditions, and the robot is not advisable to use for horizontal transfer, therefore the UAV wins in terms of cost, but loses in terms of total work time and reliability, which is affected by gusts of wind and rain, which is practically impossible to predict. For modeling transportation according to the second strategy, horizontal movement was selected by the autodrone, vertical movement to the UAV site, and from the site by the robot. This strategy significantly reduced total costs and slightly increased total time.

Thus, the combined use of various means of movement and order fulfillment with a preliminary calculation by the method of simulation modeling opens up the possibilities of using the ACS of the complex use of UAVs together with other types of unmanned technologies. If we use these indicators, then under the conditions of a single probability of delivery, we will determine the efficiency of 0.2 J/UAH. However, the absence of means of express description of spatial movement does not allow us to determine the probability of performing an operation in one way or another. In this regard, there is an urgent need to build a model of spatial movement of each type of unmanned vehicles or to find means of determining the probability of movement along a section of the trajectory without contradictions with the legislation.

In this regard, the further spread of the complex application of various types of unmanned technologies will be faced with the need to involve measurement, control and visual presentation of information-rich materials to the decision-maker. The latter is a direction for development and further improvement. Of course, for modeling and information-complete presentation on the operator interface and DM, the availability of spatial data of color-dependent visualization is attractive. In this regard, the use of software modules of color-dependent visualization of calculations of the effectiveness of alternative options for the formation of express conclusions and decision-making requires further development. The complex formulation of the problem as a task of algorithmic and software implementation due to the needs: simplicity, wide possibilities for further integration was oriented towards Python software implementation. Its use allows for quick assessments of possible scenarios and alternative comparisons, increases process efficiency, reduces the likelihood of violations and improves the manageability of operations. Complex application of functions **plot_surface(), ax_main.set_zlim(0, max_height)** together with the cmap='viridis' parameter and the list of deterministic relationships adds a color scale for convenient functional-meaningful interpretation. Data implementations for one example are shown in Figure 4.

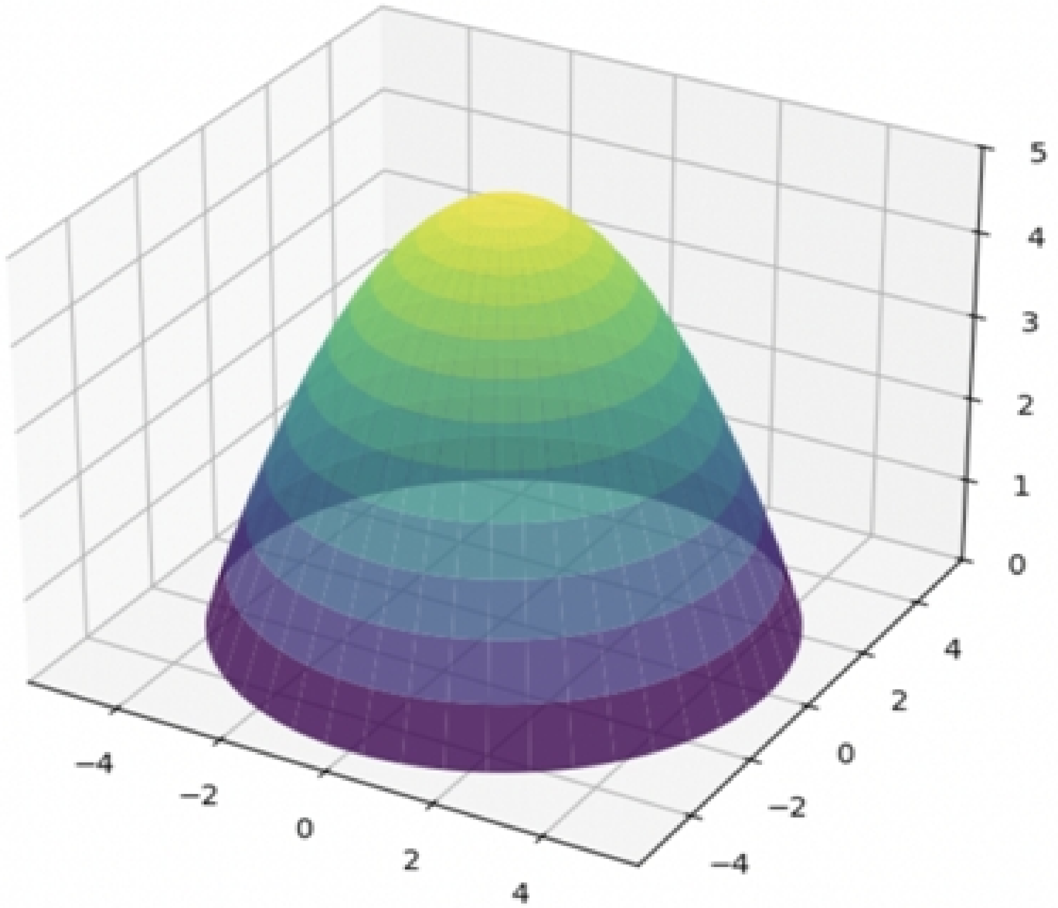


Figure 4: Result of the color-functional visualization program

This example demonstrates the capabilities and benefits application of color-dependent visualization software modules. At the same time, it clearly demonstrates the need for further improvement, taking into account the needs of frame combining and application to display complex parameters of quantitative and qualitative measurement.

Conclusions

1. Thus, the above-mentioned assessments of the needs and possibilities of civilian use of unmanned technologies form the direction of further work as a comprehensive application of a set of unmanned services, which eliminates legislative contradictions. An integral part of such development is the development of algorithmic and software modules, including color-dependent visualization, which expands the possibilities of wide domestic use.

2. The complex structure of the application of unmanned technologies and the functional scheme of the ACS TP developed on its basis allows us to involve your own and existing services in delivery chains with developed services.

3. Assessment of the functioning of the complex of services, presented by block diagrams, traffic maps, together with analytical methods for assessing the effectiveness of the operation of the node for the domestic application of unmanned technologies with the involvement of aerial and ground robotics for the implementation of an expanded list of services, provides the structure of the mathematical model of the ACS TP for their optimal involvement.

4. The integrated use of networked ground and air drones expands the types of possible services and significantly increases their efficiency and eliminates some legal conflicts with private

property and its owners, which will ultimately expand the implementation of unmanned technologies in everyday life at the expense of ACS.

Declaration on Generative AI

During the preparation of this work, the authors utilised ChatGPT and LanguageTool to identify and rectify grammatical, typographical, and spelling errors. Following the use of these tools, the authors conducted a thorough review and made necessary revisions, and accepted full responsibility for the final content of this publication.

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