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Optimisation of the choice of UAV intended to control the implementation of construction projects and works using the AHP method

Optymalizacja wyboru BSL przeznaczonego do kontroli realizacji przedsięwzięć i robót budowlanych przy wykorzystaniu metody AHP

Abstract

Modern technologies, which may include unmanned aerial vehicles (UAV, Polish abbreviation BSL), potentially have a very wide range of applications. Research has been conducted on the possibility of using UAVs to control the execution of construction works by the authors of the article among other researchers. The technical parameters of the applied measurement instruments are of great significance. This paper presents a possibility for the optimal choice of unmanned aerial vehicles using the AHP method. The popularity of this method results not only from its effectiveness in solving complex decision problems, but also from its transparency and ease of application. The decision-making analysis adopts the criteria that are essential with regard to the supervision of construction works which they may support.

Keywords: unmanned aerial vehicles, multi-criteria optimization, making decisions, decision models

Streszczenie

Nowe technologie, do których można zaliczyć bezzałogowe statki latające (BSL), mają potencjalnie bardzo szerokie zastosowanie. Prowadzone są badania, także przez autorów artykułu, nad możliwością wykorzystania BSL do kontroli wykonania robót budowlanych. Istotne znaczenie mają parametry techniczne zastosowanych urządzeń pomiarowych. W pracy zaprezentowano możliwość optymalnego wyboru bezzałogowych statków latających przy zastosowaniu metody AHP. Popularność tej metody wynika nie tylko ze skuteczności w rozwiązywaniu złożonych problemów decyzyjnych, ale również przejrzystości i łatwości stosowania. W analizie decyzyjnej przyjęto kryteria mające kluczowe znaczenie ze względu na nadzór robót budowlanych, który mogą wspomagać.

Słowa kluczowe: bezzałogowe statki latające, optymalizacja wielokryterialna, podejmowanie decyzji, modele decyzyjne

1. Introduction

The availability of unmanned aerial vehicles (UAV) affects the increase in popularity of such systems. Currently, the area of potential applications of this type of technology is constantly growing [1]. The aim of this article is to present the parameters and specifications of selected unmanned aircraft and present the possibility of choosing an optimal model UAV for use in the process of monitoring the implementation of linear building objects using the AHP method. The authors have identified criteria which may be of crucial importance as a result of the specific examination of selected construction projects. According to the authors of this study, the selection of the optimal UAV will improve the efficiency of identifying potential hazards that may occur during the implementation of the project.

UVAs coupled with appropriate cameras and sensors allows data of interest to be recorded. The advantage of this method is primarily economic efficiency, accuracy and measuring speed [2]. The authors have also carried out studies on the use of UVAs in other areas of construction engineering, these are described, inter alia, in the work [3]. In recent years, the use of unmanned aircraft has become an innovative method of taking measurements. Unmanned aerial vehicles equipped with high resolution cameras are able to inspect construction objects precisely [2]. Furthermore, the lack of negative impact in the use of UAVs on the environment and the low risk of damage in the event of a vehicle failure make it possible to conduct flights over facilities in urban areas [4]. In literature, one can find a wide range of possible applications of UAVs described both in quantitative and qualitative research.

2. Possible applications of unmanned aerial vehicles in construction engineering

In attempting to choose the optimal UAV, the authors identified criteria which are essential in the process of monitoring the implementation of linear building objects (see also [3]). The first criterion is the speed of flight, which often translates into flight range. The flight speed is crucial for the professional supervision of a large area. In general, the more professional the equipment, the longer the flight and operation time. Another criterion enabling the operation of the device in an open space is the range of the remote control device, this is usually around 2 km. In the event of loss of communication between the transmitter and the receiver, an unmanned vehicle has the function for self-return to a pre-designated location. In the case of executing longer observations, it is worth purchasing equipment capable of operating in the air up within a maximising the time that the UAV can operate [5].

The maximum flight distance is one of the most important criteria when measurements are made over a wide area. UAV operation time in the air depends on the weight of a model, the batteries and other components [3]. Thus, weight is a significant parameter which relies mainly on the dimensions and material from which a UAV is produced. It should be emphasised that during long-distance cruises, it is important that a UAV is made of a suitable material in order to meet monitoring requirements, for example, concerning flight distance. It is the weight of a UAV that determines whether a vehicle is characterised by stability and strength when in the air. The analysis assumes that heavier UAVs should offer the possibility of hanging off heavier measurement equipment. The fifth criterion identified by the authors is the maximum flight altitude.

When flying at a certain altitude, a shot from directly above can be obtained of virtually the entire construction site, especially in hard-to-reach places. A UVA's ability to rise to the desired altitude enables the creation of 3D models of selected objects or simply the photographing of certain areas and the subsequent creation of maps. The last criterion is the possibility of connecting sensors and detectors which are included in UAV equipment. Unmanned aircraft can be equipped with a range of sensors that provide data to the operator. The most frequently used sensors are: an accelerometer; a gyroscope; an ultrasonic sensor; a pressure sensor; a vertical camera measuring the velocity over ground. The nature of the conducted study makes it necessary to assess not only whether a UAV meets certain criteria, but also to what extent they are met. Not all criteria are equally relevant for a decision maker. The fundamental issue is, therefore, the specification of the criteria that are essential and will allow decision-makers to choose the optimal UAV which should support the execution and supervision of construction works [6].

3. Principles of the AHP method

The AHP method was used to choose the optimal UAV – this is one of methods of multi-criteria analysis. The AHP method was developed and described by T. L. Saaty [7, 8]. Based on works [9] and [10], with this (as is the case with works [11–13]), the authors presented only the most important theoretical assumptions of the AHP.

In principle, this method should help to make optimal choices in the case of multi-criteria optimisation due to their reduction to a series of pairwise comparisons [9]. Since the characteristic feature of the method is the fact that elements in pairs are compared with each other, the rating scales applied as standards are generally of very limited use. For this reason, a new nine-point grading scale has been introduced [8].

In order to evaluate the elements at particular levels of the analysed structure a matrix of comparisons A with elements a_{ij} $(i,j = 1, 2, \dots, n)$ was constructed, in which the order n is the number of elements being compared, wherein, if the criterion K_i is equivalent to the criterion K_j, then $a_{ij} = 1$ and $a_{ji} = 1$. In other cases, if $a_{ij} = z$, then $a_{ji} = 1/z$ for $z \neq 0$ [9].

All elements of the model under analysis are organised by importance of priority vectors $W = w_1, \dots, w_n$. To make a calculation of a priority vector W, the matrix A must first be normalised by dividing each of its elements by the sum of the elements of the column in which it is situated (then the matrix $B$is created) [9]:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{1}$$

Thereafter, the average values are determined for each matrix row, being elements w_i of the priority vector W [9]:

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \tag{2}$$

where $i, j = 1, \ldots, n$, wherein $\sum_{i=1}^{n} w_i = 1$. The symbol k_i is applied in the case of the priority vector of the analysed criteria, while the symbol o_{ij} is used for the priority vector of the i^{th} object according to the criterion j^{th}.

The value of the coefficient AHP marked h_i is determined based on the relation [12]:

$$h_i = \sum_{i=1}^{n} (k_i o_{ij}), \tag{3}$$

where k_i is the value of the element of the priority vector for the i^{th} criterion (the so-called i^{th} criterion weight), while o_{ij} is the value of the element of the priority vector for the j^{th} object with respect to the i^{th} criterion, wherein $\sum_{i=1}^{n} h_i = 1$.

Therefore, it can be stated that particular criteria and analysed variants are compared through determining the degree of superiority of one element over another. These operations are quite subjective; therefore, they can be characterised by a lack of consistency in the assessment.

In the AHP method, the reliability of results is verified primarily by determining the consequence ratio CR calculated according to the formula [9]:

$$CR = \frac{CI}{RI} 100\%, \tag{4}$$

wherein RI is a random index dependent on the matrix order n (e.g. if $n = 6$, then $RI = 1.24$) [9]. The consequence index CI is determined from the relation [9]:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)}, \tag{5}$$

where λ_{max} is the maximum eigenvalue of the matrix, which is always greater than or equal to the matrix order n.

The approximate maximum eigenvalue of the matrix λ_{max} can be calculated as the sum of products of the average row values of standardised weights and column sums corresponding to the individual criteria, which can be written with the expression [10]:

$$\lambda_{max} = \sum_{i=1}^{n} \left(w_i \sum_{j=1}^{n} a_{ij} \right). \tag{6}$$

It was assumed that if the value of the consequence ratio CR exceeds 10%, then the whole process of assessment should be repeated [9].

4. The application of the AHP method in the process of the optimal choice of UAV

The main objective of the performed analyses was to choose the most optimal UAV, taking into account the established criteria. Six variants of solutions to this problem were adopted for the analyses, as shown in Table 1. In the example under consideration, six criteria were assumed, these include: the flight speed (K1); the maximum flight distance (K2); the range of the controller (K3); the weight (K4); the maximum flight altitude (K5); the number of detectors and sensors belonging to UAV equipment (K6).

Table 1. Data of unmanned aerial vehicles selected for the analysis

Name of the selected model		**The selected criteria**					
		K1	**K2**	**K3**	**K4**	**K5**	**K6**
		[m/s]	**[min.]**	**[km]**	**[kg]**	**[km]**	**[no.]**
DJI Inspire 1 PRO	W1	22.00	18.00	2.00	2.90	4.50	0.00
ParrotAR.Drone 2.0	W2	16.00	15.00	0.05	0.44	0.10	4.00
DJI Phantom 3 Standard	W3	16.00	25.00	1.00	1.22	0.50	4.00
Tornado H920	W4	21.00	24.00	2.00	5.00	1.00	5.00
Yuneec Typhoon H	W5	10.00	22.00	1.00	0.19	0.12	2.00
Quadcopter Matrice 100 DJI	W6	22.00	22.00	2.00	0.24	0.17	3.00

Formula (2) was used to specify the values of the priority vector k_i for the adopted criteria – these are presented in Table 2 as the importance coefficients (i.e. weights) of these criteria. The subjective assessment expressed by the priority value k_i showed that the most important criterion in the selection process is the range of the controller (K3), while the least significant criterion – the flight speed (K1).

Table 2. Weights of criteria adopted for analyses

Specification		**K1**	**K2**	**K3**	**K4**	**K5**	**K6**	**The priority vector k_i**
flight speed	K1	1.000	0.200	0.167	0.250	0.502	0.334	0.048
maximum flight distance	K2	5.000	1.000	0.833	1.249	2.502	1.666	0.238
range of a controller	K3	5.988	1.200	1.000	1.499	3.003	2.000	0.286
weight	K4	4.000	0.801	0.667	1.000	2.003	1.334	0.191
maximum flight altitude	K5	1.992	0.400	0.333	0.499	1.000	0.666	0.095
number of detectors and sensors	K6	2.994	0.600	0.500	0.750	1.502	1.000	0.143
The value of the consequence ratio CR = 0.00%								

Table 3 presents the evaluation of particular variants (types of UAVs) in accordance with the six adopted criteria. In this case, the table also shows the values of the priority vector o_{ij} for each of the variants obtained using formula (2).

Table 3 presents the values of the consequence ratio *CR* defined by formula (4). Having performed the analysis of the value of this ratio, it can be stated that the assessment of individual variants were very consistent, since the value of *CR* was far below 10%.

Table 4 presents the final results of the calculations performed according to formula (3). The results unequivocally prove that the *Tornado H920* (W4) is the optimal UAV in the considered computational conditions. Obviously, these conclusions can also be reached intuitively however, using the AHP method, numerical values are obtained that can be used for further analysis.

Table 3. Assessment of individual variants according to the established criteria

Specification		W1	W2	W3	W4	W5	W6	Priority vector o_{i1}	Consequence ratio *CR*
Assessment of the variants according to criteria K1									
DJI Inspire 1 PRO	W1	1.000	1.370	1.370	1.050	2.220	1.000	0.206	0.00
Parrot AR. Drone 2.0	W2	0.730	1.000	1.000	0.770	1.620	0.730	0.150	
DJI Phantom 3 Standard	W3	0.730	1.000	1.000	0.770	1.620	0.730	0.150	
Tornado H920	W4	0.952	1.299	1.299	1.000	2.110	0.950	0.195	
Yuneec Typhoon H	W5	0.450	0.617	0.617	0.474	1.000	0.450	0.093	
Quadrocopter Matrice 100 DJI	W6	1.000	1.370	1.370	1.053	2.222	1.000	0.206	
Assessment of the variants according to criteria K2									
DJI Inspire 1 PRO	W1	1.000	1.200	0.720	0.750	0.820	0.820	0.142	0.41
Parrot AR. Drone 2.0	W2	0.833	1.000	0.600	0.625	0.680	0.680	0.118	
DJI Phantom 3 Standard	W3	1.389	1.667	1.000	1.670	1.140	1.140	0.215	
Tornado H920	W4	1.333	1.600	0.599	1.000	1.090	1.090	0.177	
Yuneec Typhoon H	W5	1.220	1.471	0.877	0.917	1.000	1.000	0.174	
Quadrocopter Matrice 100 DJI	W6	1.220	1.471	0.877	0.917	1.000	1.000	0.174	
Assessment of the variants according to criteria K3									
DJI Inspire 1 PRO	W1	1.000	33.330	2.000	1.000	2.000	1.000	0.248	0.00
Parrot AR. Drone 2.0	W2	0.030	1.000	0.060	0.030	0.060	0.030	0.007	
DJI Phantom 3 Standard	W3	0.500	16.667	1.000	0.500	1.000	0.500	0.124	
Tornado H920	W4	1.000	33.333	2.000	1.000	2.000	1.000	0.248	
Yuneec Typhoon H	W5	0.500	16.667	1.000	0.500	1.000	0.500	0.124	
Quadrocopter Matrice 100 DJI	W6	1.000	33.333	2.000	1.000	2.000	1.000	0.248	
Assessment of the variants according to criteria K4									

DJI Inspire 1 PRO	W1	1.000	6.440	2.420	0.580	14.500	11.600	0.290	0.00
Parrot AR. Drone 2.0	W2	0.155	1.000	0.375	0.090	2.250	1.800	0.045	
DJI Phantom 3 Standard	W3	0.413	2.667	1.000	0.240	6.000	4.800	0.120	
Tornado H920	W4	1.724	11.111	4.167	1.000	25.000	20.000	0.500	
Yuneec Typhoon H	W5	0.069	0.444	0.167	0.040	1.00	0.800	0.020	
Quadrocopter Matrice 100 DJI	W6	0.086	0.556	0.208	0.050	1.250	1.000	0.025	
Assessment of the variants according to criteria K5									
DJI Inspire 1 PRO	W1	1.000	50.000	9.090	4.550	33.330	25.000	0.704	0.00
Parrot AR. Drone 2.0	W2	0.020	1.000	0.180	0.090	0.670	0.500	0.014	
DJI Phantom 3 Standard	W3	0.110	5.556	1.000	0.500	3.670	2.750	0.078	
Tornado H920	W4	0.220	11.111	2.000	1.000	7.330	5.500	0.155	
Yuneec Typhoon H	W5	0.030	1.493	0.272	0.136	1.000	0.750	0.021	
Quadrocopter Matrice 100 DJI	W6	0.040	2.000	0.364	0.182	1.333	1.000	0.028	
Assessment of the variants according to criteria K6									
DJI Inspire 1 PRO	W1	1.000	0.003	0.003	0.002	0.005	0.003	0.001	0.02
Parrot AR. Drone 2.0	W2	400.000	1.000	1.000	0.800	2.000	1.330	0.221	
DJI Phantom 3 Standard	W3	400.000	1.000	1.000	0.800	2.000	1.330	0.221	
Tornado H920	W4	500.000	1.250	1.250	1.000	2.500	1.667	0.277	
Yuneec Typhoon H	W5	200.000	0.500	0.500	0.400	1.000	0.667	0.111	
Quadrocopter Matrice 100 DJI	W6	333.333	0.752	0.752	0.600	1.499	1.000	0.169	

Table 4. Results of calculations by the AHP method

Variants	Name of the selected model	The value of the AHP ratio – h_i
W1	DJI Inspire 1 PRO	0.200
W2	Parrot AR. Drone 2.0	0.095
W3	DJI Phantom 3 Standard	0.160
W4	Tornado H920	0.283
W5	Yuneec Typhoon H	0.100
W6	Quadrocopter Matrice 100 DJI	0.162

5. Conclusion

Unmanned aerial vehicles have highly diversified technical features, which determines the need to select specific criteria for their assessment. The correctness of carried out analyzes is dependent on these criteria. The presented issues based on the method of multi-criteria optimisation is possible to be used in the broadly understood civil engineering, particularly in the context of the supervision of construction works and monitoring the progress of work on a construction site [14–18]. Due to the application of the AHP method, the obtained numerical values clearly show that the best-suited device for this type of projects is the *Tornado H920.*

In the AHP method, the rating scale for quantitative criteria is actually difficult to implement. In this paper, the rates received during the pairwise comparisons of individual decision variants were expressed as the ratio of values of individual criteria. The overall conclusion is that the adopted AHP method is an option for choosing the optimal UAV, but not an option that is recommended. It seems more reasonable to take advantage of methods directly using the values of individual criteria for the comparison process, for example, the Bellinger methods, as presented in paper [3].

References

[1] Cavoukian A., *Privacy and Drones: Unmanned Aerial Vehicles*, Information and Privacy Commissioner of Ontario, Canada 2012.

[2] Kowalski P., Bielecki K., *Zastosowanie termowizji z wykorzystaniem dronów w budownictwie*, http://www.inzynierbudownictwa.pl (access: 07.03.2016).

[3] Skorupka D., Duchaczek A., Waniewska A., Kowacka M., *Optimization of the choice of unmanned aerial vehicles used to monitor the implementation of selected construction projects*, Proceedings of the International Conference on Numerical Analysis and Applied Mathematics 2016, ICNAAM-2016, Simos T.E., Tsitouras C. (eds.), Numerical Analysis and Applied Mathematics, Rhodes, Greece, 19.09–25.09.2016.

[4] Sobolewski J., *Wykorzystanie dronów do oblotu sieci elektroenergetycznych*, http://www.rynek-gazu.cire.pl/pliki/2/wykorzystaniedronowdooblotusiecielektroenergetycznych.pdf (access: 07.03.2016).

[5] http://www.dji.com/product/phantom-4 (access: 07.03.2016).

[6] Audronis T., *Drony. Wprowadzenie*, HELION, Gliwice 2015.

[7] Saaty T.L., *Some Mathematical Concepts of the Analytic Hierarchy Process*, Behaviormetrika, 29, 1991, 1–9.

[8] Saaty T.L., Vargas L., *Models, Methods, Concepts and Applications of the Analytic Hierarchy Process*, Kluwer Academic Publishing, Boston 2001.

[9] Ostręga A., *Sposoby zagospodarowania wyrobisk i terenów po eksploatacji złóż surowców węglanowych na przykładzie Krzemionek Podgórskich w Krakowie*, Ph.D. thesis, Faculty of Mining and Geoengineering, AGH University of Science and Technology, Kraków 2004.

[10] Teknomo K., *Analytic Hierarchy Process. Kardi Teknomo's Homepage*, http://people.revoledu.com/kari/tutorial/AHP/AHP.htm (access: 07.03.2016).

[11] Duchaczek A., Skorupka D., *Evaluation of probability of bridge damage as a result of terrorist attack*, Archives of Civil Engineering, 2013, 59(2), 215–227.

[12] Skorupka D., Duchaczek A., *Metoda oceny ryzyka uszkodzeń obiektów komunikacyjnych w warunkach kryzysowych (Damage risk assessment method of bridge objects in conditions*

of crisis), [in:] *Inżynieria przedsięwzięć budowlanych: rekomendowane metody i techniki*, Kasprowicz T. (ed.), Warsaw University and Technology, Publishing House: Section of Engineering Projects Construction KILiW PAN: Polish Chamber of Civil Engineers, 2015, 209–228.

[13] Duchaczek A., Skorupka D., *A Risk Assessment Method of Bridge Facilities Damage in the Aspect of Potential Terrorist Attacks*, Periodica Polytechnica Civil Engineering, 2016, 60(2), 189–198.

[14] Kapliński O., Janusz L., *Three phases of multifactor modelling of construction processes*, Journal of Civil Engineering and Management, 2006, 12(2), 127–134.

[15] Kasprowicz T., *Cost-time scheduling of construction works execution*, J. Infrastructure Planning and Management, 2000, 660 (IV–49).

[16] Połoński M., *The analysis of the reliability of realization cost and investments, time-limits in Warsaw*, Electronic Journal of Polish Agricultural Universities Topic Civil Engineering, 2006, 9(4), #10.

[17] Sobotka A., Czarnigowska A., *Analysis of supply system models for planning construction project logistics*, Journal of Civil Engineering and Management, 2005, 11(1), 73–82.

[18] Plebankiewicz E., Leśniak A., *Overhead costs and profit calculation by Polish contractors*, Technological and Economic Development of Economy, 2013, 19.1, 141–161.