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INTERPRETING DEVELOPMENT OF UNMANNED AERIAL VEHICLES USING SYSTEMS THINKING

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ABSTRACT

Rapid present development of unmanned aerial vehicles is rather unstructured. Starting from general systems theory we formulate classification of unmanned aerial vehicles (UAVs) that properly groups diverse produced unmanned aerial vehicles, along with their currently unproduced, yet possible types. First we structure the context of applications of UAVs using systems thinking. Secondly, we divide UAVs according to their function in environment: transfer of mass, energy and information. Thirdly, we further divide UAVs following with exchanges between them and environment which do not perform UAVs main predicted function. Fourthly, we analyse possible types of UAVs and divide them based on the structure of their lift-creating element, on their regulating programmes, and on the type of their power-plant.

We deduce guidelines for researchers and practitioners regarding prospective focuses in the field of unmanned aerial vehicles.

KEY WORDS

unmanned aerial vehicles, UAV, transfer of mass, transfer of energy, transfer of information, system, classification

CLASSIFICATION

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INTRODUCTION

Unmanned Aerial Vehicle (UAV) is an object capable of flying without carrying a human pilot during flight. We consider that UAVs include Unmanned Aircrafts [1] as well as other flying bodies. Nowadays, UAVs usually form a part of Unmanned Aerial Systems (UAS) [1, 2].

In recent years and, according to predictions, in near perspective, their development is of considerable proportions both in quantity and quality. Their applications cover a broad range of tasks which were previously conducted by aircrafts carrying human pilots, which have been conducted with simpler aerial devices, or which were previously conducted without flying objects. Examples of types of UAVs that we refer to in this article range from semi-autonomous and guided aircrafts or balloons, to guided rockets, to unguided balloons, to unguided rockets and projectiles.

It may come as no surprise that underlying development of UAVs is rather stochastic, occurring independently in many institutions, in many areas of application, accompanied with research and development covering a large number of disciplines.

Attempts to develop classification of UAVs have been undertaken since some time ago. As a rule, these attempts have resulted in the classification based presumably on mass of UAVs [2-7]. Mass serves as a scalar criterion for classification and is certainly an important UAVs parameter. UAV’s mass is partially influenced by number of devices and instruments that UAVs carry, by its construction, by type of lift-creating elements and by targeted flight endurance. Furthermore, overall UAV’s mass is connected with costs for manipulation and maintenance of UAVs, etc. In that way it is a parameter that aggregates many influences and that is sensitive to changes in all of them.

However, classification based presumably on UAVs mass does not make possible distinction of various functions of UAVs, does not enable one to infer about UAVs further characteristics. Moreover, it does not provides one with a solid basis for analysing influence of a particular UAVs sub-system, or attributed function onto the overall efficiency of UAV and it does not contribute to simplifying conduction of efficiency and other technological analyses of UAVs. To illustrate of these points, Figs 1 and 2 relate two UAVs flight characteristics (flight duration and flight velocity) with their mass (corresponding numerical values are given in the Appendix). Finally, from the system point of view, classification based on mass is unrelated to some general technical principles. Before proceeding, let us note that classification base on mass does not end on it, but further introduces sub-groups of UAVs based on the character of their function: (i) tactical UAVs, (ii) strategic UAVs, (iii) special task UAVs and (iv) other UAVs [2, 7], as well as further sub-sub-groups.

Classification of UAVs that as a starting point takes into account several of UAVs’ characteristics would, therefore, contribute to clearer overall view of UAVs research and development, to more efficient isolation of inefficient phases in development, to ranking of different types of UAV applications based on their prospectiveness, and generally to improved understanding of trends and perspectives of development which are most important parts of UAVs for non-technical sectors such as are commercial use, legislation, etc. To state that differently, better adaptation of UAV’s production to the context of their use would benefit from the UAV classification which utilises more than one classifying parameter [8, 9].

Second section elaborates structure of UAV-classification scheme. Third section presents the compact graphical representation of the formulated classification. Perspectives for the UAV’s development, as inferred from the formulated classification, are given in the fourth, concluding section.

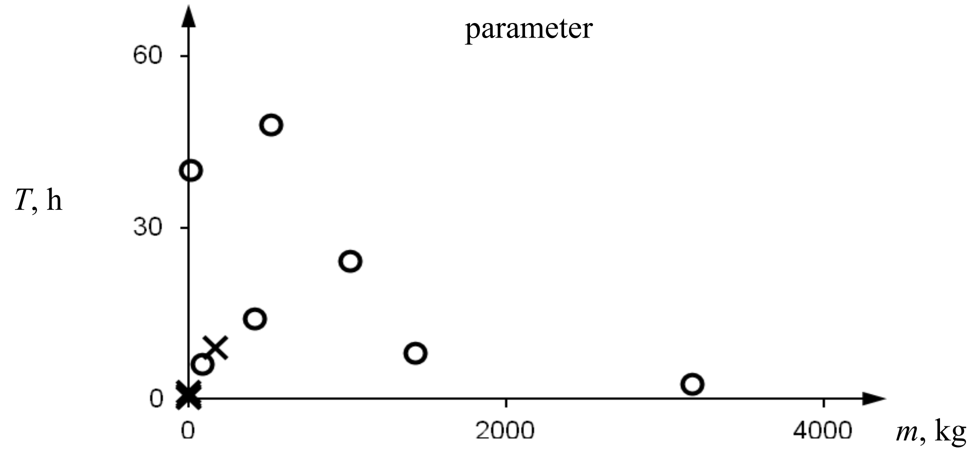

Figure 1. Relation of UAV's flight duration (T) to their mass (m) for two types of power-plants: crosses denote electric motors as power-plants and circles fossil-fuel engines.

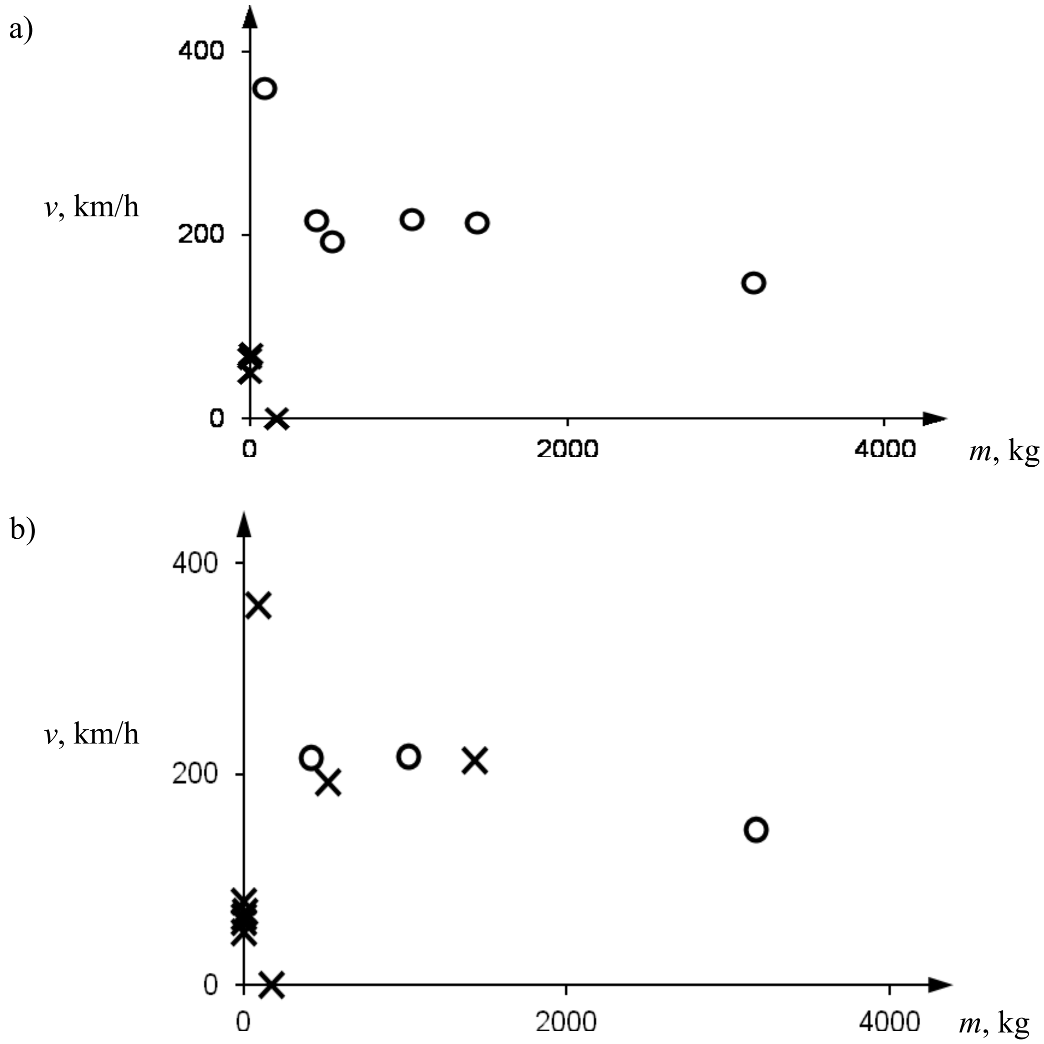

Figure 2. Relation of UAV's maximal velocity relatively to atmosphere during horizontal flight (v) and their mass (m), a) for two types of power-plants: crosses denote electric motors as power-plants and circles fossil-fuel engines, b) for two types of transfer: crosses denote primary transfer of information and circles primary transfer of mass (described further in the text).

UNMANNED AERIAL VEHICLES CLASSIFICATION BASED ON SYSTEMS-THINKING

CONTEXT OF UNMANNED AERIAL VEHICLES' FUNCTIONING

Starting point of the classification is that any single UAV is a system. That fact may look as a trivial one, or can be misinterpreted having in mind the existing notion of UAS. Despite its appearance, that fact has profound consequences.

For if an UAV is a system, one may argue that it is opportune to apply onto it the systems thinking, or other methodologies from General Systems Theory. In particular, any system is functioning in a given environment with which it has transfers. Transfers are divided into transfer of mass, energy and information [10]. The system has its function in a given environment and we relate fulfilment of that function with realisation of transfers. Such transfers are further in the text denoted as primary transfers. There can be additional transfers of mass, energy and information between system and its environment, which are not closely related to fulfilment of its function. We treat such transfers separately from the transfer related closely to the system's function, and denote them as secondary transfers. To summarise, the primary transfer is conducted via UAV between different parts of UAV's environment, while secondary transfers occur between UAV and its environment. In other words, primary transfer is the one in which the UAV figures as a subsystem of a broader, larger-scale system while secondary transfer is the one in which the UAV is a system in a given environments. Taking explicitly into account the further level, the sub-systems of an UAV, is of interest for aiming to completeness of the classification.

Mentioning of the environment is by no means sufficient, as for a useful classification further dividing the environment is needed. Here we treat environment as consisting of host, target, obstacles and atmosphere, Fig. 3. Host consists of launching facilities, system for tracking and guiding an UAV, as well as of further elements needed to enable the UAV its predicted functioning. Element target is any part of environment onto which an UAV performs a given function. Elements obstacles are any artificial, human-made elements or systems which influences in a negative way capability of UAV's functioning. Finally, element atmosphere is physical space with its weather, including other natural influences onto UAV's performance. Generally, stated elements are mutually different elements. However, in some cases it may happen that one element performs more than one function. Examples are when an UAV collects some data from the atmosphere in case of which target and atmosphere coincide. In many defensive applications target is enemy or hostile location the facilities of which include diverse obstacles to UAV's functioning.

Before proceeding, let us remark that a system consists of elements mutually connected with relations because of what in the case of UAVs we consider the elements to be lift-creating elements, power-plant, energy source and governing algorithm (programme). Relations are again considered as transfers of mass, energy and information, but this time as internal transfers.

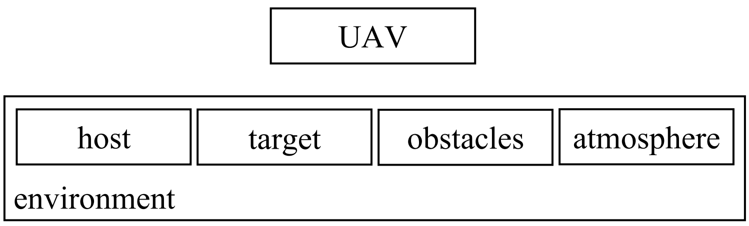

Figure 3. Context of functioning of an UAV.

UNMANNED AERIAL VEHICLES' PRIMARY TRANSFERS

The first criterion for UAV classification is: primary transfer conducted during regular UAV's performance. Possibilities are that primary transfer is transfer of mass, transfer of energy or transfer of information, all between UAV and target. That criterion relates the UAV to their function in environment.

Transfer of mass is realised, e.g. when an UAV carries materials that target needs from host, e.g. medicines, food, construction materials, ammunition, etc. Along with the other defensive applications, transfer of mass includes carrying of explosive ordnances which are predicted to destroy a target, but without simultaneous destroying the UAV. Mentioned examples cover net input of mass from host to target. Examples of transfer of mass with net input of mass from target to host cover possible collecting of materials for diverse purpose such as research, etc. The aerial applications cover collecting the air samples during flight. In all applications insofar listed, all elements from Fig. 2 are separate elements. Other cases are also possible. For example, let us assume a possible situation that first a host sends and UAV with food and medicine to target, and secondly that UAV returns to host carrying further objects, and some mass in general. Then that second action is not a net transfer of mass from target to host but again a transfer of mass from host to target with the peculiarity that control facilities of a host are identical as target. Overall, transfer of mass here means a single transfer, to be contrasted with multiple transfers of a mass which in fact falls into other types of transfer. A particular example of use of UAVs as aerial bombs, the use that was prevalent in early development of UAVs, falls into primary transfer of mass in which host, target and obstacle coincide.

Transfer of energy includes both directions of net input of energy: from host to target and the other way around. There is no prescribed type of energy transferred so in general it can be chemical, mechanical, heat energy, etc., with single, double of multiple types of energy transferred during one application. Projectiles and bombs are examples of UAVs that transfer energy from host to target. Possible application in which UAV carries tools and conducts some work at the target falls in this category. Corresponding examples include drilling rocks at high altitudes, limbing or cutting trees, etc. The other type of transfer of energy includes collecting the energy from atmosphere. So, UAVs with solar panels, either with fixed-wings of significant span, or balloons and airships, fall in this category. Additional applications of this kind are UAVs that collect wind-energy, or use energy of thermals. In such applications the atmosphere is the target. Collected energy is transferred to ground host. Let us remark that to this category does not belong the case of an UAV that utilises the collected energy for its own endurance. Such a case refers to details of energy source as an UAV's element, and not to its primary transfer.

Transfer of information is the prevalent primary transfer of diverse UAV's applications. It includes collecting of information from target for defence, scientific and other purposes. That is the net input of information from target to host. Depending on the application, the secondary transfer of information to the target may need to be suppressed, in applications like are defence applications, eco-system applications, etc. In such applications, along with the predicted information flow from target to host, there can be restrictions for other simultaneously occurring transfers. Since other transfers are covered by secondary transfers, that topic will be covered in the next section.

Use of UAVs for transferring information from host to target includes applications for telecommunication purposes. An UAV may serve as an aerial access point, making possible communication among several locations, in principle of non-determined number. The collection of such locations serve as distributed element figuring simultaneously as host and target, since their pervading is too intense, during usually rather small time intervals, to make possible separation of the locations into either the hosts or the targets.

SECONDARY TRANSFERS RELATED TO UNMANNED AERIAL VEHICLES

These are transfers that accompany primary transfer, or that occur independently to it. Presumably, to that category belongs the transfer between the UAV and host.

Secondary transfer of mass is rather an exception than a regular case of UAV's use. It is so because the mass restrictions for UAVs are rather stringent, so a lot of efforts in construction phase and during exploitation is involved in order to suppress the unwanted wasting of rather scarce UAV's energy onto transfer of ballast.

Similarly, secondary transfer of energy is rather rare compared to primary transfers of energy. On the one hand, regularly encountered losses of energy (e.g. waste heat and noise) are usually accompanied with the omnidirectional fluxes. Their suppression or channelling is the important task during the UAV's construction. We will not include these transfers explicitly in further considerations, but will consider them implicitly as a separate characteristic of a particular UAV's subsystem, presumably of UAV's power-plant. Another type of secondary energy transfer includes cases in which UAVs collect energy from environment. These cases may be absorbing the solar energy, utilisation of horizontal air streams such as winds or jet streams, or utilisation of vertical air stream as is thermal convections, all for enhancing the UAV's flight endurance. Currently, examples of UAVs which collect total or significant portion of working energy from environment are rather scarce. Along with the fact that R&D in that area will possibly bring about significant achievements in near future, let us note that it is the first step in developing the use of UAV for primary transfer of energy.

Information transfer is the prevalent secondary transfer. For guided UAVs it is constant during their flight. We will cover some possible situations regarding other possibilities of secondary information transfer. For example, in many defence applications an UAV should not be detected by the target, or any other group which does not belong to the host. That imposes restrictions onto the visibility of the UAV, height of its flying during the mission, radar cross section minimisation, etc. On the other hand, an UAV exploited in a defence missions can be of minimal achievable dimensions, if that suits the need for the UAV to penetrate geometrically confined regions such as buildings' interiors. Such UAVs are visibly and auditory detectable, so their perseverance depends on their manoeuvrability. Information transfer can be, in diverse applications, of restricted access to all parties but the host. That imposes additional restrictions. On the one hand these fall into the detectability problem for an UAV, while on the other hand it may happen that the very detectability of an UAV is not a problem, but that intercepting of the transferred information should be restricted. We consider the question of intercepting to be a software problem, not related to primary or secondary transfer of UAV and its sub systems.

UAV SUB-SYSTEMS

As was listed previously, the sub-systems of UAVs that we cover explicitly are lift-creating elements, power-plant, energy source and governing algorithm (programme).

Lift-creating elements are divided, in accordance with the aircrafts with human crew, into static buoyancy elements and dynamic buoyancy elements. Static buoyancy elements are volumes of balloons and airships. In the context of creation of lift, we do not further differentiate balloons from airships, as their difference is caused by guidance and manoeuvrability. Elements of dynamics buoyancy are wings, and we further differentiated UAVs with wings fixed for other parts and UAVs with wings that can move regarding to other parts. Into the former group falls airplane-like UAVs and in the later the rotorcraft-like UAVs, such as helicopters and quadrotors. In principle, hybrid construction is possible that combines volume for static lift and wings for dynamics lift.

While most of the types of UAVs have power-plant, some types still do not have separate power-plant but their motion is obtained in other ways. Ballistic projectiles use inertia for motion, gliders and launch-and-forget meteorological balloons use dynamic and static lift, respectively, etc. Non-ballistic projectiles exploit rocket motors as a degradable power plant. Its degradation because of use is well adapted to its guidance and overall flying capabilities. Rocket motors are further divided, but that is out of the scope of this classification. Other types of power plant include internal combustion engines, turbo-engines, electric motors, etc. A particular case of sport leisure and toy UAVs, in particular the small flying models, include intermittent, small-power power sources, such as is rubber tape.

Energy source sub-system is important because of the overall importance of energy efficiency. We differentiate autonomously powered UAVs from environmentally supported UAVs. In the former class belong all UAVs that carry their own fuel, whether that be fossil fuel or source of electric energy. Examples of the later case, environmentally supported UAVs, are UAVs that partially or completely obtain energy for flight endurance from the environment, like are previously mentioned solar-powered UAVs, gliders or balloons.

Governing algorithm's characteristics important for this classification are first whether it exists. If it exists, second characteristic is whether it works autonomously during UAVs flight or not.

COMPACT CLASSIFICATION

Previously elaborated aspects of UAVs are grouped as shown in Table 1. Classification is utilised as follows. First letter, a capital one, denotes the UAV's primary transfer. Second and possibly other letters, all small, denote secondary transfers if they exist, with more important additional letter being more to the left in the sequence. Slashes separate sub-system characteristics, in the following order from left to right: lift-creating elements, power-plant, energy source and governing algorithm. Letters after slash denote main characteristics of subsystems. Slashes are written only to the last non-blank notation.

Table 1. Notations for primary and secondary transfers of UAVs.

Transfer	Mass	Energy	Information
Primary	M	E	I
Secondary	m	e	i

Table 2. Notations for UAV's sub-systems.

Sub-system	Lift-creating element	Power-plant	Energy source	Governing algorithm
Notation	F – fixed wings R – rotating wings B – balloon (blank) – none	(blank) – none D – fossil fuel engine E – electric motor O – other types	I – inertia E – electric energy A – environment (atmosphere) K – fossil fuel	A – autonomous flight G – guided flight (blank) – none

To illustrate notation in Tables 1 and 2, a solar-powered controlled balloon serving as aerial access point is denoted as I/B/E/A/G, a ballistic projectile is denoted as M, etc. In particular, more examples of realised UAVs are given in Table 3.

Table 3. Examples of classifying some of the existing UAVs.

UAV	Source	Classification
Wasp block III	http://www.avinc.com	Im/F/E/E/A
GNAT-750	http://www.designation-systems.net/dusrm/app4/gnat.html	Im/F/D/K/G
MQ-1 Predator	http://www.af.mil/information/factsheets/factsheet.asp?fsID=122	MI/F/D/K/G
RQ-4 Global Hawk	http://en.wikipedia.org/wiki/Northrop_Grumman_RQ-4_Global_Hawk	I/F/D/K/G
RQ-7 Shadow	http://olive-drab.com/idphoto/id_photos_uav_rq7.php	I/F/E//A
MQ-8 Fire Scout	http://www.as.northropgrumman.com/index.html	I/R/D//A
Bell Eagle Eye	http://www.naval-technology.com/projects/belleagleeyeuav	I/FR/D/K/G
Draganflyer X8	http://www.draganfly.com/uav-helicopter/draganflyer-x8	I/R/E/E/G
Dassault nEUROn	http://www.dassault-aviation.com/en/aviation/press/press-kits/2012/the-neuron-makes-its-maiden-flight.html?L=1	IM/F/D/K/G
Lehmann Aviation LM450	http://www.lehmannaviation.com	I/F//I/A
FR SWAN X1	http://www.flying-robots.com/en/company/profil-de-mission.html	IM/R/D/K/G
SELEX Galileo Falco	http://selex-es.com/~/media/Files/S/Selex-Galileo/products/air/unmanned-systems/FALCO.pdf	IM/F/D/K/G
Bayraktar Mini UAV	http://www.baykarmakina.com/en/MiniUAV	I/F/E/E/G
MicroPilot MP-Vision UAV Glider	http://www.micropilot.com/products-mp-visione.htm	I/F//I/A
Kaman K-MAX	http://www.kaman.com/aerospace/helicopters	M/R/D/K/G
Parrot AR.Drone	http://ardrone2.parrot.com	I/R/E/E/G

CONCLUSIONS AND PERSPECTIVES

Presented classification aims to group from the functional point of view all possible aspects of UAVs. The classification is based on the systems thinking. That being the case, from the point of view of perspectives, we can only analyse diversifying the number of existing types (i.e. functions or applications) of UAVs in near future. Based on the search through available literature, we extract the primary energy transfer of the UAVs to be the qualitatively most prospective field of UAVs R&D in the near future.

APPENDIX

Table 4. Numerical values of UAV's characteristics shown in graphs in Figs 1 and 2.

UAV	Maximal velocity*, km/h	Mass, kg	Power-plant power, kW	Flight duration, h
Wasp block III	65	0,43		0,75
GNAT-750	192	520	64	48
MQ-1 Predator	217	1020	86	24
RQ-7 Shadow	204	170	28	9
MQ-8 Fire Scout	213	1430	313	8
Bell Eagle Eye	360	91	478	6
Draganflyer X8	50	2,7		0,3
Lehmann Aviation LM450	80	0,95		0,55
FR SWAN X1		17		40
SELEX Galileo Falco	216	420	48	14
Bayraktar Mini UAV	70	3,5		1,3
MicroPilot MP-Vision UAV Glider	60	2,72		0,9
Kaman K-MAX	148,2	3175	1341	2,7
Parrot AR.Drone		0,42	15	0,2

*relative to the atmosphere during horizontal flight

REFERENCES

[1] The USA Department of Defense: *Dictionary of Military and Associated Terms*.
The Joint Publication 1-02 (as amended through 15 November 2012). The USA Department of Defense, 2012,
http://www.dtic.mil/doctrine/new_pubs/jp1_02.pdf,

[2] Van Blyenburgh, P.: *Unmanned Aircraft Systems. The Current Situation*.
EASA Workshop on UAV, EASA, 2008,
http://www.easa.europa.eu/ws_prod/g/doc/Events/2008/February/1-Overview%20of%20the%20UAV%20Industry%20%28UVS%29.pdf,

[3] Van Blyenburgh, P.: *UAVs – Current Situation and Considerations for the Way Forward*. RTO Educational Notes 9, RTO NATO, 1999, http://ftp.rta.nato.int/public//PubFulltext/RTO/EN/RTO-EN-009///EN-009-01.pdf,

[4] Hein, G. and De Fátima Bento, M.: *Unmanned Aerial Vehicles: An Overview*. Working Paper January/February 2008, Inside GNSS Magazine, 2008, http://www.insidegnss.com/auto/janfeb08-wp.pdf,

[5] Transport Canada Civil Aviation Unmanned Air Vehicle Working Group: Final Report. Transport Canada, 2007, http://www.tc.gc.ca/eng/civilaviation/standards/general-recavi-uavworkinggroup-2266.htm,

[6] Carbon-Based Technology, Inc.: *UAV Classification*. http://www.uaver.com/about-6-classification.html,

[7] Agostino, S.; Mammone, M.; Nelson, M. and Zhou, T.: *Classification of Unmanned Aerial Vehicles*. Project, University of Adelaide, 2006, http://personal.mecheng.adelaide.edu.au/maziar.arjomandi/Aeronautical%20Engineering%20Projects/2006/group9.pdf,

[8] DeGarmo, M. and Nelson, G.M.: *Prospective Unmanned Aerial Vehicle Operations in the Future National Airspace Systems*. Technical Paper 04-0936, The MITRE Corporation, 2004, http://wwwsrv2.mitre.org/work/tech_papers/tech_papers_04/04_0936/04_0936.pdf,

[9] Joint Air Power Competence Centre: *Strategic Concept of Employment for Unmanned Aircrafts in NATO*. UAS CONEMP Report, JAPCC NATO, 2010, http://www.japcc.de/fileadmin/user_upload/Reports/ConEmp_Jan2010/UAS_CONEMP.pdf,

[10] Ćosić, J.: *Software Development for Embedded Systems: Case Study of Unmanned Aerial Vehicles*. 1st Internet and Business Conference, Rovinj 2012.

INTERPRETACIJA RAZVOJA BESPILOTNIH LETJELICA PRIMJENOM PRISTUPA SUSTAVA

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SAŽETAK

Brzi sadašnji razvoj bespilotnih letjelica vrlo je nestrukturiran. Polazeći od opće teorije sustava postavljamo klasifikaciju bespilotnih letjelica koja pravilno grupira različite proizvedene bespilotne letjelice, kao i one vrste koje trenutno nisu proizvedene ali su moguće. Kao prvo strukturiramo kontekst primjene bespilotnih letjelica primjenjujući pristup sustava. Kao drugo, dijelimo bespilotne letjelice prema njihovoj funkciji u okolini: prijenos mase, energije ili informacije. Kao treće, dodatno dijelimo bespilotne letjelice obzirom na njihove izmjene s okolinom koje ne ulaze u njihove glavne predviđene funkcije. Kao četvrto, analiziramo moguće vrste bespilotnih letjelica i dijelimo ih prema njihovim uzgonskim elementima, regulacijskim programima i vrsti pogona. Izveli smo nekoliko smjernica za istraživače i korisnike obzirom na perspektivne smjerove razvoja bespilotnih letjelica.

KLJUČNE RIJEČI

bespilotna letjelica, UAV, prijenos mase, prijenos energije, prijenos informacije, sustav, klasifikacija