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SAFETY ENGINEERING OF ANTHROPOGENIC OBJECTS

AN EVENT MODEL OF THE OPERATION PROCESS OF UNMANNED AIRCRAFT VEHICLES USED IN THE POLISH ARMED FORCES

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Abstract

The article addresses the issue of unmanned aircraft vehicles used in the armed forces of the Republic of Poland as a technological object undergoing the exploitation process in accordance with an event-based exploitation model. The author discusses problems related to the semantics of drones, which, in conjunction with the study of technical documentation and participant observation, allowed to qualify the operating state and determine the exploitation process event model for these devices together with the permitted transitions matrix. The presented results are the basis for further research on the reliability of these systems.

Key words: exploitation process, reliability, unmanned aerial vehicles, armed force

INTRODUCTION

The Armed Forces of the Republic of Poland, in order to increase their defense capabilities, have been investing in modern aviation technologies, including unmanned aerial vehicles (UAVs). Currently, the Polish Army is in possession of five types of these devices – 15 sets of Orbiter and Fly Eye UAVs, one set of Scan Eagle, and one of RQ-21 A Blackjack, which tasks are primarily related to reconnaissance and observation. The armed forces have also been equipped with striking UAVs – Warmate. Apart from increasing the number of UAVs, Polish Armed Forces also plan to purchase nano drones. The above illustrates the growing importance of Unmanned Aircraft in the Polish Armed Forces, and thus also their relevance on the future battlefield.

Taking all the above into consideration, it should be emphasized that not only the purchase of new equipment is necessary to enhance increase the state's defense readiness, but also to maintain the existing potential. This means that all effort should be made to ensure that unmanned aerial vehicles currently in the possession of the Polish Armed Forces remained in the state of operational readiness as long as possible in readiness to carry out designated tasks. Therefore, it is necessary to perform reliability tests of these devices, taking into account the environment, in which they will be used.

It should be noted that unmanned aerial vehicles are characterized by specific attributes, when compared to aircraft directly controlled by humans (the crew). These features affect the ability to control flight and technical parameters , which have an impact on keeping the device operational.. Therefore, proper subsequent operational tasks should be identified and adequately described to systematize the process as much as possible. There is hence a need to recognize the operational states of unmanned aerial vehicles and construct its mathematical model.

The purpose of this article is to determine the event model of the unmanned aerial vehicle operation process. First of all, due to of terminology discrepancies in the subject literature, the exact subject of the study was elucidated. The next step was to determine the operational states that occur during operating of UAVs used by the Polish Armed Forces. Finally, the permitted event transition matrix was described.

The research was carried out on the basis of the analysis of technical documentation of UAVs used by the Polish Armed Forces (12th UAVs Base in Mirosławiec) and participating observation in the process of the use of the devices at the same base. The study presented in this article should be treated as an introduction to broader research that was undertaken by the author as part of her doctoral dissertation entitled "Examination of the reliability of selected elements of unmanned aircraft". The study will allow to determine external and internal factors affecting the reliability of selected elements of the technology, which, in accordance with the adopted general functional and technical structure of the UAV, will enable the increase of reliability of the whole object by a positive influence on the process of operation, service and/or construction.

THE SEMANTICSOF UNMANNED AERIAL VEHICLE

Determining the cognitive foundations of the analyzed technical object is a sine que non condition for the correct creation of states and event models of the considered objects in the considered system (reality). This is related to the complexity of technical objects. Homogeneous technical systems cause no problems, but unmanned aerial vehicles are complex systems and thus the scope of what is understood by that name should be clearly defined. In the subject literature, there are many terms that seem to describe the same segment of reality. This is also the case of unmanned aircraft ,where several terms are used interchangeably: unmanned aerial vehicles, unmanned aerial systems, radio-controlled aircraft, drones, etc.

In order to unequivocally determine UAVs' operating states, it was considered necessary to clearly define the subject of the study, i.e., unmanned aerial vehicle. The adopted for the study definition of unmanned aerial system is taken from and is formulated as following: "system whose components include the unmanned aircraft, the supporting network and all equipment and personnel necessary to control the unmanned aircraft" [1], where unmanned aerial vehicle is defined as one or more use power-driven aircraft that uses aerodynamic forces to provide lift, which flies independently or is remotely piloted, and capable of carrying lethal or incapacitating loads.

On the basis of the above definitions, it was determined that the basic UAV function is a flight performed independently or remotely. On that account, at a further stage of research, the necessary components of the unmanned aerial vehicle to perform the above function, i.e., flight were defined. Among them, there are: ground control systems (in the case of autonomous systems the programming ones), and aircraft using uplift force.

In addition, it was specified that the implementation of the flight function in reusable devices cannot take place without take-off and landing. Therefore, take-off and landing will be considered, in the considered model, as an immanent part of the flight.

Having worked out the above cognitive fundaments, it turned out possible to determine the states that occur during the operation of unmanned aerial vehicles. These states were determined on the basis of an analysis of the technical documentation of the unmanned aircraft used by the Armed Forces of the Republic of Poland (research was carried out in 12th UAV Base in Mirosławiec) and during observation of the usage of the devices carried out by specialized personnel.

UAV'S OPERATION STATES

The usage of every technological object, including unmanned aerial vehicles, is associated with carrying out by that object a series of consecutive actions. These activities are related to its intended use and the operation process specific for this technology. The operation process is described by sets of operational states [15]. A characteristic feature of the operational states is that the technological object can be, at a given time, only in one of the specified states, although with varying intensity. Having in mind the hierarchical nature of the impact of the states on UAVs' utilization, it was decided to list only key states. It was assumed that the UAVs will perform tasks from the place of permanent dislocation (transport was not included). At the same time, an assumption was adopted that the exploitation process is random, because the time the aircraft is in individual operating states is random, and the transition from one operating state is also a random event [9]. This means that the possibility of determining the most important states of occurrence and transition from state to state in the UAV exploitation process is only a probabilistic transition.

The analysis of the tasks carried out during operating unmanned aerial vehicles in the armed forces has enabled the identification of six basic operational states that constitute the basis for developing the event model.

Table. 1. UAVs' utilization states

No	Descriptions	Impact of individual states	Mutual interaction of the states
1	Ground control (programming) systems service	-	5; 6
2	Pre-flight service	5;	6
3	Performing a flight	1; 2	-
4	After-flight service	3	-
5	Periodic service	3; 4	1

6	Repairs, renovations.	5; 3; 4	2; 1

The listed operational states defined in the table above are described in more detail below [2,5,10,11]:

1. Ground control (programming) systems service – a state in which are carried out the following activities: maintenance, unmanned aerial vehicle control, control of system measurements;
2. Pre-flight service – a state in which are carried out all the activities verifying the capability of the device to perform flight. They include every operation on the device before flight, revision of documentation, ad hoc service necessitated by weather conditions, checking the level of indicators and measuring the battery charge. The periodic service has a direct impact on that state;
3. Performing a flight – a state in which an unmanned aerial vehicle is performing an aerial task. The state of operation of ground control systems, as well as pre-flight service has a direct impact on that state;
4. After-flight service – a state in which the unmanned aerial vehicle is in immediately after completion of the flight. In the state, the following operations are carried out: identification of the technical condition of the device, elimination of potential negligence of the UAV's service team, maximum elimination of malfunctions. The state of flight performance has a direct impact on that state;
5. Periodic service – a state, which is realized according to the technical documentation of the device. Service procedures are carried out in line with the established patterns/ activities at a given time (depending on the flight-hours). It is a detailed diagnosis of all UAV's subsystems, which goal is to replace inoperative or overused components. The flight performance and post-flight service have a direct impact on the state in question;
6. Repairs, renovations – a state in which the replacement of damaged components of an unmanned aerial vehicle takes place. The malfunctions can be caused by a sudden defect, failure, and other unpredictable factors. Fixing of the component takes place also at the time of probable damage during the next use. Flight performance, after-flight service, and periodic service have a direct impact that state.

Such defined states allow to specify the event model for unmanned aerial vehicles.

AN EVENT MODEL OF THE UAV'S OPERATION PROCESS

Considering the above factors affecting the possibility of unmanned aircraft staying in a particular operational state, a graph was developed to demonstrate the permitted transitions from state to state. This model was generated on the basis of the analysis of the states and operational events related to the discussed technological objects (unmanned aerial vehicles) used in the analyzed system – the armed forces. Due to the criterion of the risk regarding the operation of the analyzed object in the adopted system, and on the basis of prior identified operational states, the possible transitions between them were defined [3,4].:

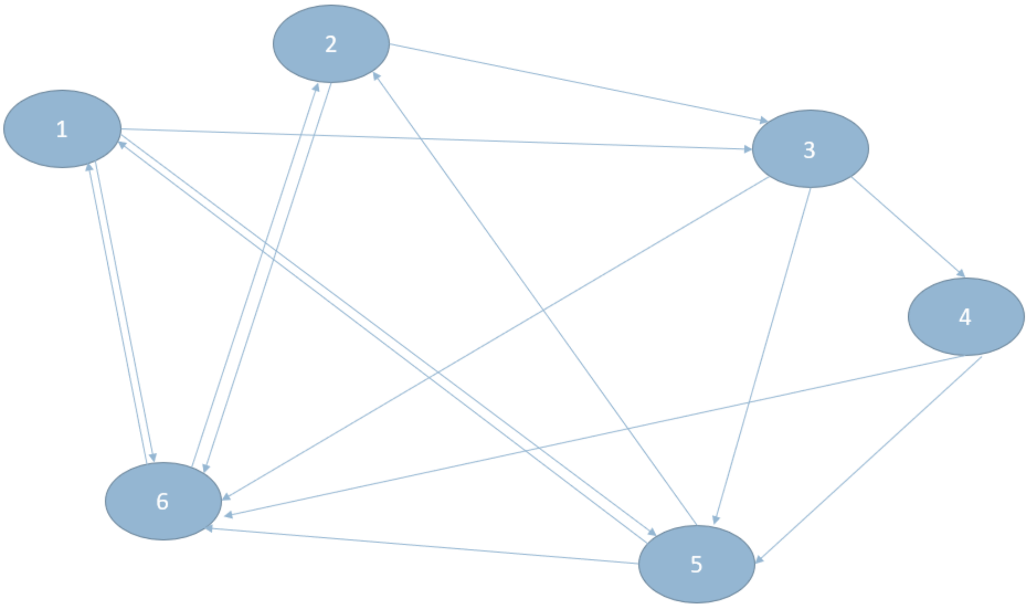

Fig. 1. Permitted transitions from state to state (own elaboration)

From a mathematical point of view, the probability of transitions was determined on the basis of the above graph. The Markov process is used for the most common probability transition process:

$$p_{ij}(s,t)=P[X(t) = j|X(s) = i] \quad (1)$$

with the assumption that: $t \geq s; i; j = 0,1,2\ldots$

The above assumption is also met by Smoluchowski-Chapman-Kolomorgov equations:

$$p_{ij}(s,t) = \sum_{k=0}^{\infty} p_{ik}\ (s,t_1)p_{kj}(t_1,t),(s > t_1 < \ t), \quad (2)$$

Bearing in mind the above, the distinction between prospective and retrospective equations is made, but the probability of passing P (t) = [pij (t)], where \ "i" and "j" are in the set "S" and "t" in the set "T"[7] is not omitted.

$$p'_{ij}(t) = -\lambda_j(t)p_{ij}(t) + \sum_{\substack{k=S \\ k\neq j}} \lambda_{ki}(t)p_{ik}(t) \quad (3)$$

$$p'_{ij}(t) = -\lambda_i(t)p_{ij}(t) + \sum_{\substack{k=S \\ k\neq i}} \lambda_{ik}(t)p_{kj}(t) \quad (4)$$

with the assumption that: $p_{ij}(0) = \begin{cases} 1\ for\ i = j \\ o\ for\ i\ \neq\ j \end{cases}$

Now, the task is to determine the matrix of the probability of state transition to a state referring to the future and to equation of convergence of variables according to the intensity of the transition. In order to do that, an axiom was adopted that the probability is unconditional at a given moment in a given state (probability of the absolutes), under the known initial conditions [12,14].

$$d_i(t)=P\{X_i=i\} \text{ for } i \in S,\ t \in T \tag{5}$$

$$\forall i \in S: d'_i(t) = -\lambda_i d(t) + \sum_{\substack{j \in S \\ i \neq j}} \lambda_{ji} d_j(t) \tag{6}$$

$$D(t)=[d_1(t), d_2(t), K, d_r(t)]_{1xr} \tag{7}$$

A matrix of intensity is then obtained assuming that "r" is the number of process states in the following form [6]:

$$\Lambda = \begin{bmatrix} -\sum_{j=2}^{r} \lambda_{1j} & \lambda_{12} & \dots & \lambda_{1r} \\ \lambda_{21} & -\sum_{\substack{j=1 \\ j \neq 2}}^{r} \lambda_{2j} & \dots & \lambda_{2r} \\ M & M & O & M \\ \lambda_{r1} & \lambda_{r2} & \dots & -\sum_{j=1}^{r-1} \lambda_{rj} \end{bmatrix} \tag{8}$$

Determination of the permitted transitions of the object from state to state was carried out on the basis of the analysis of the technical documentation of unmanned aerial vehicles and theoretical assumptions allowed to create a matrix of transitions permitted for the considered technological object.

Matrix Trj = 1 means a permitted transition, and Trj = 0 no transition.

Table 2. Matrix of the permitted transitions (own elaboration)

$\rightarrow S_j$ $\downarrow S_i$	S_1	S_2	S_3	S_4	S_5	S_6	SUM FROM
S_1	0	0	1	0	1	1	3
S_2	0	0	1	0	0	1	2
S_3	0	0	0	1	1	1	3
S_4	0	0	0	0	1	1	2
S_5	1	1	0	0	0	1	3
S_6	1	1	0	0	0	0	2
SUMS TO	2	2	2	1	3	5	15

Recapitulating the above – the presented above table shows the characteristic properties of two dimensions of the matrix. The first is the permanent limitation of the operation process due to the inability of various states to interact with each other; the second are the states of free transition from state to state. When the inability to return to the previous state was imposing, it caused a kind of protection against negative factors generated by the randomness of arbitrary transitions in the operational process [15]. The best example of a restrictive nature of the system is S4, which permits only one transition. From a theoretical point of view, the maximum number of free transitions without restrictions is, for the graph above, 25. The number of transitions from state to state, in the carried out tests of operational process, was 15.. This means that the operational process was carried out with low randomness [8] while protecting the possibility of operation against illogical use.

CONLUSION

According to experts, the increase of UAVs importance is inevitable and corresponds to the developmental trend of aviation technology. That is why it is so important that the Polish Armed Forces not only acquire new combat systems but also observe the reliability of the possessed UAVs. The reliability of UAVs is defined as the probability that it will perform its intended functions within a specified period of time and under specified conditions. It follows from the above that it is inseparably connected with operational processes that are carried out by UAVs.

Taking above in to consideration, it should be stated that it was necessary to determine the operational states. It was possible on account of previously carried out theoretical research, which determined that the main elements of the unmanned aircraft are both the aircraft itself and the ground control station, without which the intended function – flight – would not be possible. On the basis of the technical documentation, six operational states were defined, which the unmanned aircraft operated by the Polish Armed Forces are subjected to. These states were connected though graphical representation (graph) of the permitted transitions. The latter constitute the event model of the operation process of the discussed technological object.

Bearing in mind the above, it can be stated that the purpose defined in the introduction, namely, defining the event model of the unmanned aerial vehicle operation process, has been fulfilled. However, it should be once again emphasized that the conducted research is merely an introduction to further studies related to the reliability of unmanned aerial vehicles by influencing the operation process of selected elements.

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