Assessment of ergodesign level of unmanned aerial system

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Abstract

Unmanned aerial systems (UAS) are widely integrated into different sides of human activity. The effective application of UAS to complete particular tasks depends on multiple factors. The success of the UAS mission highly depends on the performance of human-to-UAS interaction. Effective UAS should meet the requirements of ergonomic design of each UAS component including ground control station, unmanned aerial vehicle, and launch-landing devices. In the paper, we develop a system to provide an assessment of the UAS ergodesign level. The proposed system is grounded on ergodesign indicators of UAS elements quality. The total level of ergodesign quality is estimated as a weighted sum of all indicators. A method of expert judgment is used to identify each indicator value. The proposed system is based on centralized software with the main analysis on server side and parameters assessment module in remote terminals. The proposed system architecture supports multiple users and participation in many tasks of UAS assessment simultaneously. Also, all data is coded with a unified user sequence and cannot be recovered.

Keywords

ergonomic design, unmanned aerial system, expert judgment method, statistical analysis, software

1. Introduction

Nowadays Unmanned aerial systems (UAS) are used in different sectors of the economy. Modern air traffic management considers UAS as an important element of future air transportation system [1, 2]. Integration of Unmanned Aerial Vehicles (UAV) in controlled airspace will significantly increase the amount of air traffic [3, 4]. Common UAS structure includes UAV, ground control station (GCS), launch and landing equipment. Normal operation of all UAS structural elements is required for successful mission completion [5, 6]. Each element of UAS has its system boundary to perform a particular task and includes multiple sub-systems that support a particular level of automation [7, 8]. A high level of UAV autonomy is one of the most important requirements for future air transportation system [9, 10].

The human factor is an important element of UAS operation which has a significant impact on UAV mission performance. Human factor could act at different levels of UAS operation that degrade normal operation and could lead to UAV loss [11, 12]. In the most common cases, human factor appeared in mistakes that happened during human-machine interaction at different UAS structural elements. The UAV specifically is connected with a speedily moved object in a dynamically changed environment that makes time of human-machine interaction is high priority in mission success [13, 14]. In manual flight control mode, the speed of human-matching data link is critical. The payload

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also requires manual control and guidance which should be provided within a defined time range [15, 16].

Another important factor is the environmental comfort of the UAS remote pilot. Operation of the remote pilot in a non-friendly environment accumulates fatigue that significantly decreases performance of the system and leads to an increasing number of mistakes [17, 18]. Therefore, ergonomic requirements are important in GCS design to minimize human disturbances, minimize the number of required human-machine interactions, and ensure a long duration of user comfort in the system.

Actually, each component of UAS requires human-mashing interaction: system deployment, mission planning, setting up of equipment, and maintenance [19, 20]. Harmful effect of human factor could act at each of these stages and degrade overall system performance [21, 22].

Ergodesign is a complex of actions that aims to minimize human factor action in UAS by achieving the required level of function comfort for human in the system loop. Ergodesign considers each element of UAS separately and provides recommendations for UAS developers in efficient system design from the human-centric side.

In the paper, we develop a set of ergodesign indicators for estimation of total system quality in satisfaction of ergonomic requirements. Also, a computerized system architecture is proposed to support ergodesign assessment process. The proposed system uses multi-user access, which uses a remote terminal for entering the data from experts and statistical data processing at the server side of the software. A maximum posterior method is used to classify the level of ergodesign in particular UAS.

The paper is structured as follows: the second section considers the main aspects of ergodesign in UAS; the third one describes a proposed method of ergodesign level assessment; the fourth section describes the architecture of the proposed computerized system; and in the numerical demonstration we use a developed system for particular UAV analysis for support ergodesign requirements.

2. Key features of UAS ergodesign

Ergonomics considers usage of knowledge about the professional activity of a person to ensure the greatest success in product (UAS) practical application [23, 24]. The intervention of the ergonomic requirements in the project, in particular, the design process, should take place as early as possible to ensure meeting requirements at each stage of UAS design. It cased ergodesign requirements to UAS.

Nowadays, ergodesign is a progressive technology related to the design and production of high-quality, knowledge-intensive, competitive products. This is a new type of design activity, different from traditional ergonomics. Its purpose is to ensure success and the required level of comfort for a person in different areas of his/her activity, which is grounded on convenience, safety, comfort, and aesthetic perfection of means and conditions of human activity [25, 26]. The result of ergodesign is not a combination of design methodology and ergonomics, but the development of new design principles and methods taking into account the real internal and external sides of operators' activities.

Ergodesign of UAS has to ensure the safety and comfort of personnel involved in UAV control, maintenance, and repair. Egrodesign grounds on the detailed study of human-machine interaction with particular parameters for optimization, such as mission duration and range of situations that could affect normal UAV flight. Time of human feedback in the UAS control loop is an important element of mission success which utilizes the design of an indication system, performance of human in the solution of a particular task, and using actuators to provide adequate human reaction.

UAS is a complex multi-level system that is grounded on a system approach during the process of its creation. Therefore, ergodesign studies of UAS and its subsystems are based on anthropometric data, functional and psychophysiological analysis of existing UAS. Special attention is given to ground control station design due to human-operator presence in the control loop. Egrodesign of GCS mostly focused on the study: human environment, operational stressors (unsatisfactory workplace ergonomics, unacceptable temperature mode, low level of organization of information flows, etc.), level of teamwork, and psychological state of persons. These factors are important for detecting ergodesign indicators of UAS quality and the formation of ergodesign requirements for the design and operation of UAS.

Tools and methods of UAS design have been rapidly developing during the last decades which requires constantly improving regulatory framework (normative documents and standards) based on results of ergodesign analysis. Also, new models of UAS could be created based on the functional principle of designing processes. Because the main system quality is based on ensuring personnel feeling of functional comfort when UAS components are perceived as a system of functional and object-spatial means that create comfortable and safe conditions for the operators.

Results of ergodesign analysis of common UAS types indicate two main problems:

- insufficient performance of electronic flight instrument system for particular operator activities;
- high time of human feedback due to the assimilation of various principles of mechanical operation in UAV control bodies.

Ergodesign considers not only problems related to the product (UAS) but also includes anthropocentric orientation of design actions performed during equipment production. In particular, it means ensuring the ability to meet the functional comfort requirements of all participants in the UAS development, repair, and maintenance.

During different phases of UAV mission operators required absolutely different information. The limited visual area of displays is used in an adaptive way to change parameters provided in GCS to the operator. In most cases of remote control in GCS, only one display is available. It is usually used as a wide display, however, it should integrate three main components:

- Flight display. Used for visualization relative location, orientation and parameters which are important for piloting of UAV in 3D space. Parameters for visualization include airspeed, altitude (pressure and geometrical), and angles of UAV orientation in space (roll, pitch, yaw, or heading). These parameters are critical for piloting UAVs in the 3D environment.
- Navigation display. Navigation data is required for UAV maintenance within a predefined mission trajectory. Most missions are performed by predefined trajectory which is specified as a set of waypoints. Navigation data is required for the operator to control the mission completion process and hold the airplane within possible airplane deviations. Navigation data includes a planned UAV trajectory depicted on the map. Also, these indications include current weather data, especially wind speed and wind direction.
- Visual display. Due to the operator being out of direct visual contact with the UAV, it is important to have visual contact with data from multiple cameras on board the UAV. Modern UAV structure consider multiple cameras usage which could be mounted on different sides of the UAV. Also, data from multiple cameras could be fused together to obtain a virtual sphere for visualization UAV environment in 360°.

All these types of information should be joined together for visualization in one display for UAV operator. Data fusion is based on the achievement of functional comfort as a criterion for the optimal intellectual and psychophysiological state of the operators in the process of its activity and as a criterion for the adequacy of components and elements of UAV to operators' individual capabilities. The quality of this data fusion is indicated by parameters: accuracy, reliability, productivity, and fatigue of operators in the system.

A specific software could compose a virtual sphere of a UAV environment with visualization on display or Virtual Reality glasses (VRG) [27, 28]. VRG is synchronized with a group of sensors inside VRG to measure the location of a human head in space. Data from sensors are used to rotate video in a virtual sphere to make the operator possibility to feel present on the UAV. The main disadvantage of this approach is the reduced resolution of end visualization. Data processing of 4K or even FullHD quality requires high computation power in both UAV and GCS which increases final system cost significantly. Also, it requires specific data channels for transmitting high-resolution video streams to GCS. In addition, most VRG available in the market cannot provide high-resolution video playing which reduces operator performance. All these factors make VRG effective in missions with low precision.

Another approach is grounded on using high-performance camera sensor installation within a gimbaled system. Gimbled system stabilizing video camera in a particular position. Also, such a system uses not only a camera but a sensor installation which includes 8K (4K) visual capture sensor and thermal sensor. The visual sensor could be equipped with a mechanical optic which is tuned automatically within specified zoom settings. This approach has specific requirements for UAV structure due to gimble placement and requires more power supply. However, as an advantage gimbal system makes it possible to use mechanical zoom of any direction, and only one high-performance datalink for video stream transmitting is required.

At the initial state of UAS ergodesign specific weight should be given for tasks of utility, safety, beauty, or convenience. These weights specify criteria for final system efficiency. Ergodesign is an initial stage of the UAS life cycle. The results of ergodesign are decisive for further system operation. Therefore, it should take into account the psychological aspects and anthropometrics of particular personnel who will operate UAS.

An important during the whole ergodesign process is the observance of complexity in single indicators. For example, the quality of data visualization is determined by indicators of accuracy and visual fatigue of human operator during reading analysis. The set of individual ergodesign indicators defines a complex ergodesign indicator, which can almost completely determine ergodesign level of UAS components.

Interaction of operators in UAS requires the usage of special indicators-criteria of quality or efficiency of the system as a whole and its individual elements. Each element of the system, as well as the entire system, should be evaluated by particular criteria. The correctness of definition in system efficiency depends on the number of single indicators that indicate the functioning of system elements. In this case, the main attention should be focused not on individual indicators, but on their structure, connections, and finding common formal properties between them. Finally, ergonomic design should be carried out according to a single efficiency criterion, to which other indicators are connected and to which these indicators are directly or indirectly subordinate. Thus, all indicators should be linked into a single system by means of a performance criterion, and its role should be considered and evaluated in relation to a particular criterion.

In most cases, for simplification, a dominant ergodesign criterion could be identified in the system based on UAS requirements (for example functionality, reliability, speed, and fatigue could be used as dominant criteria for ergodesign). An important requirement for this criterion is including a specific ergonomic design content. The weight of primary criteria utilized functional dependence in the UAS. Also, approximation of indicators to ideal ergodesign characteristics of the system could be used only in particular cases, because the level of system complexity is directly related to the human factor action in the system. Ergodesign indicators which come from requirements of human factor must be embedded in the design of UAS.

The main content of the system approach in ergodesign is to ensure wide impact with highlighted weight of each system-to-operator connection. The core idea of ergodesign is to consider design of new elements with help of algorithm which take into account human in the loop. The system approach in UAS design considers economic, structural, and design tasks from the side of the anthropocentric point of view. The total level of designed system quality should meet requirements of functional comfort as the main criteria for the optimal psychophysiological state of operators in the process of their work and the level of adequacy in UAS components to the individual capabilities of a person.

Common procedure for determining the ergodesign quality level of UAVs could include the following steps:

1. Choosing a dominant ergodesign criteria of UAS and its components by expert method;
2. With the help of notable reference samples, ergonomic design parameters of UAS components should be determined (dimensions, place for controls, means of displaying information);
3. Uses ergonomic requirements and results of expert judgment method evaluation to identify function which describes ergonomic design criteria and ergonomic parameters detect the level of ergonomic in UAS (according to individual parameters);
4. Using analytical methods to find interrelationships of ergodesign parameters with each other and their connections in the entire system;
5. Ergodesign analysis and evaluation of UAS level with the help of expert judgment method;
6. A complex criteria is identified based on values of individual criteria which are predetermined according to a number of ergodesign parameters.

The complex ergodesign criterion obtained in this way will express the maximum quality level achievable for a particular UAS type, and obtained values of ergodesign parameters will be maximized.

3. Method of ergodesign level assessment

A level of ergodesign quality of UAS could be evaluated based on a set of erdodesign indicators. Each ergodesign indicator has its particular scale which is characterized by its min and maximum values. Indicators could be classified into seven groups based on the nature of their action in the product:

1. Ergonomic;
2. Esthetic;
3. Operational;
4. Maintenance;
5. Social and culture;
6. Design-marketing;
7. Design-ecological.

Due to the high complexity of each indicator, we consider three levels of depth in indicators. Each high-level indicator utilizes the values of its children. Thus, a weighted sum is used to identify a parent indicator based on the values of its children. Standardized indicators could be used for estimation of a quality level of UAS or specific indicators could be introduced for advanced UAS design. These indicators could be evaluated for different structural components of UAS. We consider the following UAS structure: GCS, UAV, launch (LNC), and landing (LND) equipment.

The total system quality (Q_{UAS}) is estimated based on a weighted average of indicators:

$$Q_{UAS} = \sum_{k=1}^{N} w_k a_k, \quad (1)$$

where w_k is a weight of k-th indicator; a_k is a value of k-th indicator; N is a number of indicators.

In common case, equation (1) could be used in matrix form:

$$Q_{UAS} = sum(WA^T), \quad (2)$$

$$W = \begin{bmatrix} w_{GCS,1} & w_{UAV,1} & w_{LNC,1} & w_{LND,1} \\ w_{GCS,2} & w_{UAV,2} & w_{LNC,2} & w_{LND,2} \\ \vdots & \vdots & \vdots & \vdots \\ w_{GCS,N} & w_{UAV,N} & w_{LNC,N} & w_{LND,N} \end{bmatrix};$$

$$A = \begin{bmatrix} a_{GCS,1} & a_{UAV,1} & a_{LNC,1} & a_{LND,1} \\ a_{GCS,2} & a_{UAV,2} & a_{LNC,2} & a_{LND,2} \\ \vdots & \vdots & \vdots & \vdots \\ a_{GCS,N} & a_{UAV,N} & a_{LNC,N} & a_{LND,N} \end{bmatrix}.$$

where W is a weight matrix; A is a matrix of indicator values.

Each colon of matrixes W and A are associated with its structural components (in common case there are GCS, UAV, LNC, and LND).

Weights could be set by expert based on efficiency criteria specified in UAS. Also, in the case of equal impact of each indicator and common scale for indicator, weights could be estimated based on the maximum scale of each component:

$$W = ES^{-1}, \tag{3}$$

where E is a matrix of ones; S is a matrix of maximum values for each indicator.

The values of each indicator are evaluated by the method of expert judgment. Thus, a group of experts should be involved in the assessment process.

4. Computerized system of UAS ergodesign analysis

Evaluation of egrodesign quality assessment is grounded on expert method. In this case, a computerized system could be useful for supporting all the processes of expert judgment. We use a web-based assistance software developed in HTML 5 environment. A serverside of software is developed with PHP. A user interface is HTML 5 and JavaScript. The database is stored on the server side in MySQL. CSS provides reach features for a cross-platform, user-friendly interface. The structure scheme of the software is given in Figure 1.

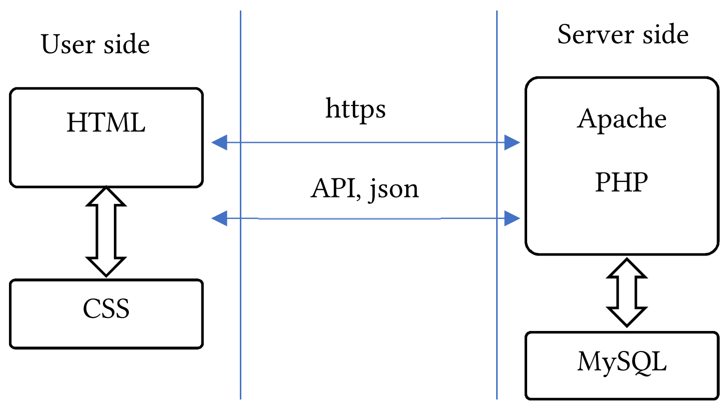

Figure 1: Structure schema of the expert judgment system.

There are two basic levels of data protection are used in the system. Encryption certificates for all data packages transferred between Server and User sides (HTTPS) are used at the initial data protection level. At the second data protection level all input values are encrypted with SHA256 and saved in the MySQL database. The results of assessments are saved in tables of the database in encrypted form. During the session user side requests values from PHP/MySQL in full coded form. A key for decoding is saved in cookies on the user side only and is used for decoding data received from the server side. Such a security approach made all data in tables coded by user-based crypto-keys which could not be recovered. Even if someone could have access to the database, results of assessments are secured. It helps to protect user-based data even from personnel who serve the server side.

Each user in the system has a particular login and password for authentication in the system. Then the user could create his/her own ergodesign assessment project or join an already present project as an external expert by secured link. Users who create a project could manage the levels for ergodesign assessments of UAS, also should specify the type of UAS and main structural components used in assessments. After each expert finishes his/her tasks a final result could be available in the system. As an example, the user interface for the assessment of UAV is given in Figure 2.

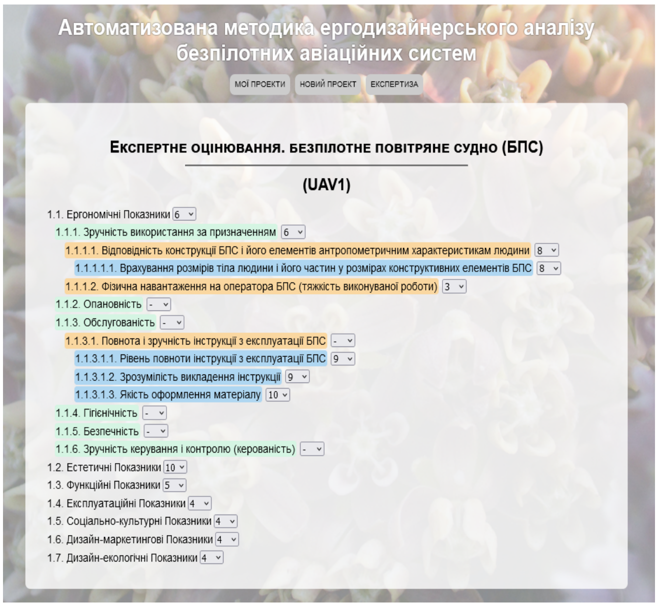

Figure 2: User interface of the proposed assessment system.

We use a 1 to 100 present range for total UAS quality. Thus, weights are recalculated automatically to get the tuning of each indicator scale. Obtained results indicate a total quality with each UAS component quality, which helps developers to integrate obtained results of assessments into the design of new UAS version with component improvements, which are identified with low ergodesign trends. Multiple iterations could be needed to get the required levels of ergodesign quality.

Also, the proposed system supports ergodesign level monitoring during the full cycle of UAS operation. In this mode of assessment, the operator and other personnel are asked to complete a questionnaire about the experience of human-UAS interrogation. Multiple assessments of one UAS could be evaluated and statistically processed. It makes possible to get multiple evaluations of one system with different personnel. The obtained results could be useful for UAS improvements.

The developed system has been used for the evaluation of ergodesign quality of UAV developed by the quadcopter scheme. We use 31 experts involved for ergodesign level of UAV evaluation. Also, several experts made assessments multiple times, after each time of operation with UAV. In total 42 assessments have been recorded in the system of a particular UAV. A histogram of the results of assessments is represented in Figure 3.

Also, we apply a statistical analysis of results with a normal probability density function (NPDF) and a kernel PDF. NPDF is characterized by mean and standard deviation parameters. Results of NPDF and KPDF are given in Figure 4.

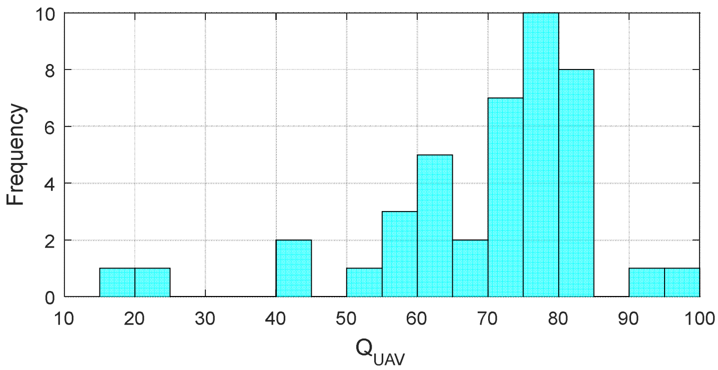

Figure 3: Results of total system quality estimation.

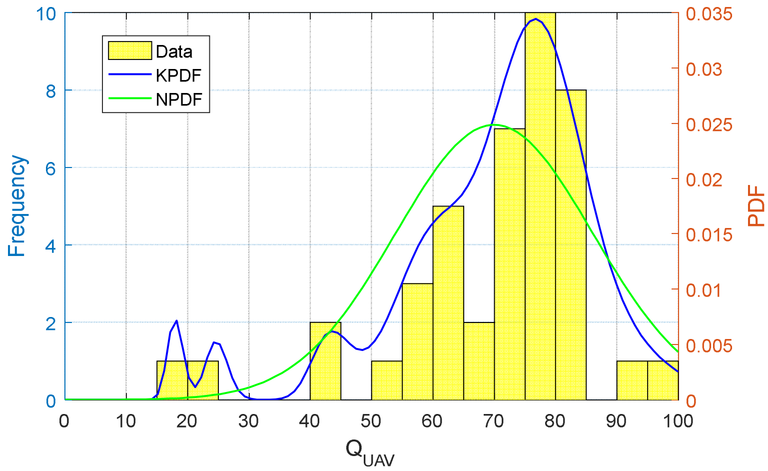

Figure 4: Results of statistical analysis of UAV ergodesign quality.

Obtained results indicate that the results of the expert judgment are not distributed normally. It means that KPDF could be used for more precise identification final confidence band for UAV quality level.

5. Conclusions

The human factor is an important component of the UAS operation cycle. Minimization of human factor action could be reached with the help of ergodesign analysis. Ergodesign analysis helps to evaluate the quality of UAS and its components based on set of unified indicators. Statistical analysis of UAS ergodesign quality helps to identify ways for system improvement and minimization of human factor action. An improved system will be more efficient for mission completion by taking into account ergonomic requirements. Ergodesign is an important task of the modern UAS development process.

The proposed computerized system for ergodesign quality estimation is a useful tool for the minimization of human factor in the UAS operation cycle. Web-based technology with an adaptive interface made a cross-platform application with minimal requirements for hardware and strong two levels of data protection from unauthorized access.

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Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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