Concept of Aircraft Flight Safety Management Using Artificial Intelligence

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Abstract

The article proposes a new concept of building an intelligent aircraft control system, which increases the functionality of the system for its adaptation to the controlled object. Enhanced adaptive system functionality is knowledge-based to help pilots perform important and safety-critical tasks on modern aircraft. The implementation of the proposed system is based on the pilot's situational awareness of the flight progress in real time, which allows avoiding errors and maintaining enhanced synergy between human and avionics systems. These synergies provide significant improvements in overall flight control performance and safety. Appropriate mathematical models are introduced to assess the mental load associated with each piloting task and assess the pilot's cognitive abilities and condition.

Keywords: flight safety, aircraft, intelligent aviation system, accident threat, prevention, control system, artificial intelligence.

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Süni intellektdən istifadə etməklə hava gəmisinin uçuşunun təhlükəsizliyinin idarə olunması konsepsiyası

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Xülasə

Məqalədə, sistemin nəzarət olunan obyektə adaptasiyasına görə onun funksional imkanlarını yüksəldən hava gəmisinin idarə olunmasının intellektual sisteminin qurulmasının yeni konsepsiyası təklif edilir. Adaptasiyaya görə sistemin funksional imkanlarının yüksəldilməsi müasir təyyarələrdə uçuşların təhlükəsizliyi nöqteyi nəzərindən pilotlar tərəfindən mühüm və kritik məsələlərin həllində onlara kömək məqsədilə biliklərə əsaslanmışdır.Təklif olunan sistemin realizəsi real zaman rejimində uçuşun gedişi barəsində pilotun şəraitə (situasiyaya) bələd olması əsasında həyata keçirilir. Bu isə səhvlərdən qaçmağa və insanla avionika sistemləri arasında geniş sinergizmi dəstəkləməyə imkan verir. Bu sinergiyalar təyyarənin idarə olunmasının ümumi məhsuldarlığını və təhlükəsizliyin səviyyəsini əhəmiyyətli dərəcədə yaxşılaşdırır. Müvafiq riyazi modellər təyyarənin idarə olunmasının hər bir məsələsi ilə bağlı olan zehni yükün və pilotun vəziyyətinin, həmçinin onun koqnitiv qabiliyyətinin qiymətləndirilməsi üçün daxil edilirlər.

Açar sözlər: uçuş təhlükəsizliyi, təyyarə, intellektual aviasiya sistemi, qəza təhlükəsi, idarəetmə sistemi, süni intellekt.

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Концепция управления безопасностью полета воздушного судна с использованием искусственного интеллекта

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Аннотация

В статье предлагается новая концепция построения интеллектуальной системы управления воздушным судном, которая повышает функциональные возможности системы по ее адаптации к контролируемому объекту. Повышение функциональной возможности системы по адаптации основано на знаниях, чтобы помочь пилотам в выполнении важных и критичных с точки зрения безопасности полетов задач на современных самолетах. Реализация предлагаемой системы осуществляется на основе ситуационной осведомленности пилота о ходе полета в реальном времени, что позволяет избежать ошибок и поддержать расширенный синергизм между человеком и системами авионики. Эти синергии дают значительное улучшение общей производительности управления полетом и повышение уровня безопасности. Соответствующие математические модели вводятся для оценки умственной нагрузки, связанной с каждой задачей пилотирования, и оценки когнитивных способностей и состояния пилота.

Ключевые слова: безопасность полетов, летательные аппараты, интеллектуальная авиационная система, угроза авиационных происшествий, предотвращение, система управления, искусственный интеллект.

Introduction

At present, an urgent problem is the question of the rational use of the achievements of scientific and technological progress in the field of complex systems based on artificial intelligence (AI). AI is a field of science that deals with the creation of machines and computer programs that allow solving intellectual problems by modeling intelligent behavior. The relevance of intelligent systems lies in the need to reduce the human factor on the control object while maintaining a high level of safety and reliability during its technical operation, which is of particular importance in the aviation industry [1-5]. An even greater challenge in the aviation industry is solving aircraft control issues based on strong intelligence. Experts are of the opinion that equipping artificial intelligence with pre-formed rules will ensure the proper safety of passengers and crew of aircraft.

Intelligent Flight Control (IFC) is defined by autonomous adaptive control algorithms that can find non-trivial solutions to control problems using trivial strategies. Conventional civil aviation autopilots are not adaptive (a human pilot must act if something unexpected happens), autonomous systems must be able to adapt themselves to changing circumstances. This is where intelligent flight control systems come in.

The flight management system (FMS) currently used in aircraft is one of the key elements of a modern aircraft. This is a computer system that helps the pilot to perform various routine operations. The FMS includes numerous artificial intelligence algorithms to support aircraft navigation, guidance and control. The FMS implements algorithms for determining the location of an aircraft using navigation aids data and combining data from several sensors.

The operation of each system of a modern aircraft is associated with the use of numerous digital computers. Each of these systems uses some elements of artificial intelligence at different levels of control and data processing. All automatic control functions can be attributed to artificial intelligence. In general, system control is based on a well-defined mathematical model of the process and a set of parameters, each of which can be polled to change the state of the system.

Intelligent flight control is based on two apparently unrelated knowledge. The first is rooted in the classical analysis of aircraft stability, control and flight quality. The second follows from human psychology and physiology. Thus, there is a need to find new control structures that are consistent with the causes of situations that have arisen in flight, and bring flight control systems to a higher level of adaptation to the controlled object.

Statement of a question

The aim of the work is to create methodological foundations for aircraft flight safety management as a set of principles, methods and algorithms for assessing the threat of an aviation accident, its prediction and countering, which are implemented as part of the functioning of an intelligent aviation system and make it possible to increase the efficiency and safety of aircraft control carried out in difficult flight conditions.

To achieve this goal, it is necessary to solve the following tasks: propose the structure of the intelligent aviation system; to carry out a system analysis of the intelligent aviation system; develop a methodology for the safety of aircraft management.

Solution - development of an intelligent aviation system. An intelligent aviation system (IAS) is proposed, developed on the basis of the aviation transport system, which is a complex of interacting systems, the functions of which are aimed at ensuring the life cycle of the aircraft.

The structure of the onboard intelligent flight control system is shown in Fig.1 [5].

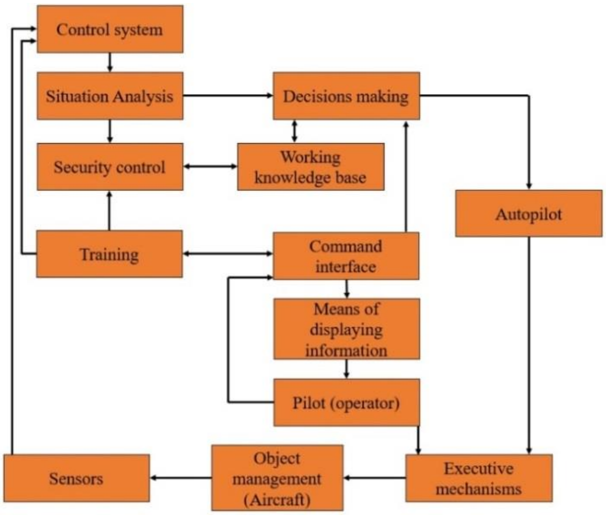

Figure 1 – The structure of the onboard intelligent flight control system

Let us consider the functions of individual modules of the system (Fig. 1), which have the property of intelligence and ensure the choice and implementation of the best flight control strategy under conditions of uncertainty. The analysis module receives sensory information about the situation from aircraft sensors. This information is displayed by the control system, which highlights situations that are significant from the point of view of decision-making, and, based on the results of the forecast, evaluates the severity of the hazard. The development of situations is predicted using the security control module. This module helps prevent the right decisions from being made before real threats emerge.

Through the command interface and flight information display (FID) systems, the pilot receives advisory information, which is generated by the decision-making module. On the basis of this information, the pilot exerts control actions applied through the autopilot directly to the aircraft actuators, taking into account the nature of the development of the situation.

Formed control options that can be changed and refined as current information is updated are contained in the working knowledge base (KB). The decision-making module and the working knowledge base together form a dynamic expert system (DES). ensuring the coordinated operation of all modules of the onboard IMS and the formation of solutions in real time. The formation or correction of knowledge bases is provided by the training module. The results of the correction are used in the modules for analyzing the situation and forecasting situations.

The command interface performs the interaction of the pilot with the aircraft, informing the pilot, on the one hand, about the state of the control object and the environment through on-board information systems, and, on the other hand, influencing the aircraft and its systems using various means and controls [6]. It should be noted that modern sensors used in aircraft are mainly built on the basis of microprocessors and therefore they are usually called intelligent devices.

To ensure the operation of the system as a whole, it must include a link that integrates the remaining links. The characteristics of a person allow him to be such a link, since a person can adapt to various conditions, relying on intuition, he is able to make decisions quickly, without having a choice of options. However, it must be borne in mind that a person gets tired very quickly when performing monotonous actions. This. as well as many of the shortcomings of a person can be compensated by automatic devices with a rational distribution of functions between the pilot and the autopilot.

System Analysis of Intelligent Aviation System. An intelligent aviation system belongs to organizational and technical systems, therefore, it has the characteristics of technical and organizational systems. These properties determine the basic principles of the functioning of the IAS, which are aimed at managing the safety of the aircraft flight.

Complex organizational and technical systems (for example, aviation and transport systems) are characterized by a large array of input multidimensional data that affect the safety of their operation, taking into account their heterogeneity. It is the use of artificial intelligence methods and system analysis that makes it possible to process such data. In addition, artificial intelligence tools are widely used in operator decision support systems in such systems. Based on this, the development of methods for assessing and predicting the threat of an aviation accident based on direct control of changes in the values of variables affecting flight safety using artificial intelligence tools is an urgent scientific problem. The solution of this issue will make it possible to identify the immediate causes of the accident and take appropriate measures to parry these accidents.

System analysis is carried out on the basis of a predictive control model (PMC) of an aircraft flight based on an effective intelligent algorithm. The improvement of the predictive model of aircraft flight is considered when flying in the longitudinal direction. The intelligent control algorithm is mainly designed to study and improve the PMC parameters based on the minimization of various time intervals of the objective functions. The proposed model of the aircraft takes into account the dynamics of the aircraft and the restrictions imposed on it. Non-linear aircraft dynamics, gust-driven disturbances, parameter uncertainty, and environmental changes are considered major obstacles to aircraft control to ensure good flight performance.

Development of an aircraft control safety methodology based on a predictive control model. An accurate mathematical model of an aircraft is considered an important first step to analyze and control an aircraft system that can be used to solve control and stability problems. The resulting model changes flight characteristics that are used for surface control and flight system design. Correcting the direction and altitude of the aircraft with less error during its flight is the main goal of control. In this case, the goal of control in the process of flight dynamics is to correct the direction of the aircraft around its center. The definition of flight dynamics is summarized as the science of guiding air vehicles and the task of steering around certain three dimensions called pitch, roll and yaw control [7]. The block diagram of the PMC flight control is shown in Fig.2. Flight control is based on a predictive control model.

This model includes a block of predictable control variables that are compared with the initial values of the variables. The difference signal is transmitted to the optimizer, which receives the values of the cost function and the constraint at the same time. The optimizer signal is transmitted to the aircraft and thus the system output is formed.

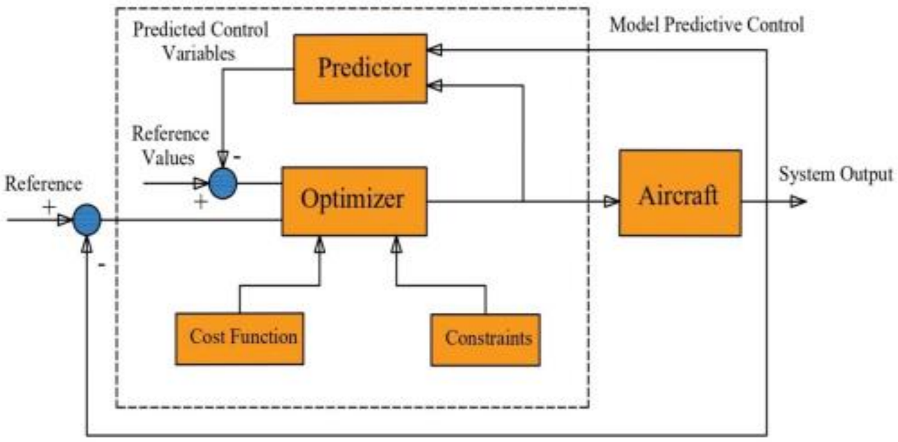

Figure 2 – MPC fight control block diagram

An intelligent control algorithm is proposed as a powerful and intelligent method for solving the problem of setting PMC parameters to improve their performance [8].

This algorithm is considered one of the most effective algorithms for tuning parameters of various types of controllers for many practical applications. The algorithm has important features such as working with multiple parameters that are used for initialization when parameters with fewer than other types of algorithms are used. Another important advantage is that the convergence rate does not depend on the parameters used. The algorithm requires several tuning factors to reduce the longitudinal deviation of aircraft motion from non-linear aircraft dynamics, gust interference, parameter uncertainty, and environmental changes.

The proposed PMK as an effective controller that can cope with uncertainty, nonlinearities and disturbances is used for aircraft control tasks. The MPC based on an intelligent algorithm is used to control the longitudinal movement of the aircraft in order to reduce low-frequency vibrations. The function of the algorithm is to find the best PMC parameters based on the decay of various objective functions in the time domain. Basically, the PMC calculations are performed at each sampling time, which can be configured by the control system designer. These calculations depend on measurements and prediction of upcoming output values. There are two calculation styles in MPC: the first one is the calculation of the setpoints, the second one is the control calculations. Control calculations contain process limits and other parameters that you can set manually.

Control calculations depend on reducing predicted deviations from the command trajectory. The main idea of the MPC strategy is shown in Fig. 3.

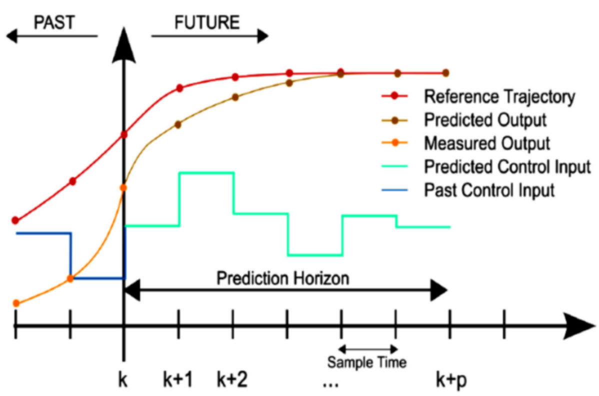

Figure 3 – The idea behind the MPC strategy

On the left side of the ordinate axis, the values of the variables at the previous point in time are indicated, on the right side, the predicted values.

Different colors on the graph indicate: prediction horizon, trajectory curve, predicted output, measured output, predicted entry control, previous controlled entry.

The action of the MPC controller depends on a mathematical representation called the cost function (J(k)). The mathematical representation of system constraints and the cost function is presented below [9, 10]:

$$J(k) = \sum_{i=1}^{P} Q.\left[\hat{y}(k+i|k) - r(k+i|k)\right]^2 + \sum_{i=0}^{M-1} R.\left[\Delta u(k+i|k)\right]^2$$

Given that:

$$y_{min} \leq \hat{y}(k+i|k) \leq y_{max}$$

$$u_{min} \leq u(k+i|k) \leq u_{max}$$

$$\Delta u_{min} \leq \Delta u(k+i|k) \leq \Delta u_{max}$$

In the equations above, the prediction horizon is denoted as P and the control horizon as M. Discrete time as k, i-interval indicator P, Q, and R denote the inference error weights and the change in the manipulated variable, respectively.

In addition, and r(k+i │ k) represent a prediction and a command based on the output at time k+i, respectively.

In addition, u(k+i │ k) and Δu(k+i │ k) represent the best prediction based on the manipulated variable and the prediction rate of the manipulated variable at time k+i, respectively.

The proposed MPL controller will receive a signal from the control stick and set the control stick point value in inches as a system input to represent the system control signal. Pilot joystick command values are selected as stepped, multi-step, and square wave signals. The MPC strategy is used to predict the control signal depending on the stick signal and the stick inch setpoint as system input. The proposed control design was developed using the MPC toolkit in Matlab.

Taking into account the sampling time period (Ts) and the number of applied control signals (N), the MPC methodology will operate at a certain rate equal to 1/N*Ts. You need to know that the choice of suitable T is important, as it calculates the length of the prediction step. In addition, the behavior and performance of the MPC is inevitably affected by the choice of P and M. In addition, there are two numerical weight parameters, Q and R, which must be carefully chosen for the input and output of the system, respectively. As a result, an intelligent algorithm is used to obtain the best Ts, P, M, Q and R values.

This study is focused on tuning the parameters of the MPC to control the longitudinal flight of an aircraft using an intelligent algorithm. The main goal of optimization is to identify the optimal parameters of the MPC that improve the damping characteristics of the onboard system by reducing the integral absolute error in time.

Conclusion

The concept of building an intelligent aircraft control system is considered, which increases the functionality of the system for its adaptation to the controlled object and helps pilots make the right decisions when performing important and critical tasks from the point of view of the flight safety of modern aircraft. This concept is based on the creation of a predictive control model as an effective controller that can cope with uncertainty, non-linearities and disturbances, used for aircraft control tasks. An intelligent algorithm-based MPC is used to control the longitudinal motion of an aircraft in order to reduce the longitudinal deviation of the aircraft's motion from the non-linear dynamics of the aircraft, interference from gusts of wind, parameter uncertainty and environmental changes.

Conflict of Interests

The author declare there is no conflict of interests related to the publication of this article.

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