UDC 681.5 (045)

[1]V. N. Azarskov,
[2]L. S. Zhiteckii,
[3]A. Yu. Pilchevsky,
[4]K. Yu. Solovchuk

ROBUSTNESS PROPERTIES OF THE ℓ_1-OPTIMAL LATERAL AUTOPILOT OF PI TYPE

[1]Aircraft Control Systems Department, National Aviation University, Kyiv, Ukraine
[2,3,4]Division of the Automated Systems for Data Processing, Int. Centre of Int. Tech. & Syst., Kyiv, Ukraine
E-mails: [1]azarskov@nau.edu.ua, [2]leonid_zhiteckii@i.ua, [3]terosjj@gmail.com, [4]solovchuk_ok@mail.ru

Abstract*—This paper deals with the design of the ℓ_1-optimal digital autopilot needed to control of the roll for an aircraft under an arbitrary unmeasured disturbances. This autopilot has to achieve a desired lateral motion control via minimizing the upper bound on the absolute value of the difference between the given and true roll angles. It is ensured by means of the two digital ℓ_1-optimal controllers of PI type. The main result consists in establishing the fact that the autopilot can be robust in the presence of parametric and nonparametric uncertainties.*

Index Terms—Aircraft; lateral dynamics; digital control system; discrete time; stability; ℓ_l-optimization; robustness.

I. INTRODUCTION

The problem of efficiently controlling the motion of an aircraft in a non-stationary environment capable to ensure its high performance index is important enough from the practical point of view [1]. To solve this problem, the different approaches based on the modern control theory, including adaptive and robust control, neural networks, etc., have been reported by many researches [2] – [7].

One of the efficient methods devised in the modern control theory for rejecting any unmeasured disturbance is based on the l_1-optimization concept [8] – [10] applicable to discrete-time control systems. Recently, this concept has been utilized in [11] to design the digital lateral autopilot of the PI type for an aircraft capable to cope with a gust.

In order to implement the l_1-optimization of any digital controller, we need the information with respect to the dynamics model of a plant to be controlled including its structure and parameters. In practice, however, it may not be available in full detail. In this real situation, the following two questions naturally arise. First, is the l_1-optimal PI controller designed via the use a priori knowledge of the so-called nominal lateral dynamics model robust? Second, how sensitive is this controller to variations of the sampling period?

This paper extends the approach which we have first reported in [11] to deal with the l_1-optimal autopilot for the lateral motion control. But, in contrast with [11], the aileron servo dynamics are taken into account to ensure the stability of closed loop. The main effort is focused on studying the robustness properties of this autopilot to parametric and nonparametric uncertainties.

II. PROBLEM STATEMENT

Let $\dot\gamma(t)$ and $\xi(t)$ denote the roll rate angle and the aileron deflection of an aircraft, respectively, at a time t. According to [12, chap. 3] the lateral dynamics equation of an aircraft derived from the linearized lateral equation of the aircraft motion can be described by the continuous-time transfer function

$$W_\xi(s) = \frac{1}{s}\tilde W_\xi(s) = \frac{K_\xi}{s(T_\xi s+1)}, \qquad (1)$$

where K_ξ and T_ξ are the aerodynamic derivatives (more certainly, T_ξ is the damping derivative in the roll channel and K_ξ is the roll moment).

As in [12, chap. 4], it is assumed that continuous-time transfer function describing the aileron servo dynamics is

$$W_S(s) = \frac{K_S}{T_S s+1}, \qquad (2)$$

where K_S and T_S are its gain and time constant, respectively.

Define by $d(t)$ an external signal (in particular, a gust) disturbing the angular velocity $\dot\gamma$. This signal plays a role of some unmeasurable arbitrary disturbance. Without loss of generality, it is assumed that it has to be upper bounded in modulus. This implies that

$$|\dot d(t)| \le C_{\dot d} < \infty. \qquad (3)$$

Suppose that $K_\xi, K_0, K_S, T_\xi, T_S$ in (1) and (2) are known, whereas $C_{\dot{d}}$ in (3) may be unknown, in general.

Defining now the output error $e(t)$ as

$$e(t) = \gamma^0(t) - \gamma(t), \tag{4}$$

where $\gamma^0(t)$ denotes the desired roll orientation at the time t, introduce the performance index of the control system to be designed in the form

$$J := \limsup_{t\to\infty} |\gamma^0(t) - \gamma(t)|. \tag{5}$$

The aim of the controller design may be written as the requirement

$$\limsup_{t\to\infty} |e(t)| \to \inf_{\{u(t)\}}, \tag{6}$$

where (4) and (5) have been utilized. The controller satisfying (6) is called optimal.

The question that we need to answer in this paper is as follows. Can this controller be robust?

III. Digital Lateral Autopilot Design

A. Control strategy

To implement the controller design concept proposed in this paper, two feedback loops similar to that in [11], [12] are incorporated in the autopilot system, as shown in Fig. 1. But, in contrast with [12], they are designed as the discrete time closed-loop control circuits using two separate controllers. To this end, two samplers are incorporated in the feedback loops; see Fig. 1. These samplers are needed in order to convert analogue signals $\dot{\gamma}(t)$ and $\gamma(t)$ in digital form at each nth time instant $t = nT_0$ $(n = 0, 1, 2, \ldots)$ to producing the discrete-time signals $\dot{\gamma}(nT_0)$ and $\gamma(nT_0)$, respectively, with the sampling period T_0. On the other hand, the signal $u(nT_0)$ formed by digital controller at the same time instant converts to analogue form $u(t)$ using the so-called zero-order hold (ZOH) [13]. This makes it possible to represent the control input, $u(t)$ as follows:

$$u(t) = u(nT_0) \quad \text{for} \quad nT_0 \le t < (n+1)T_0.$$

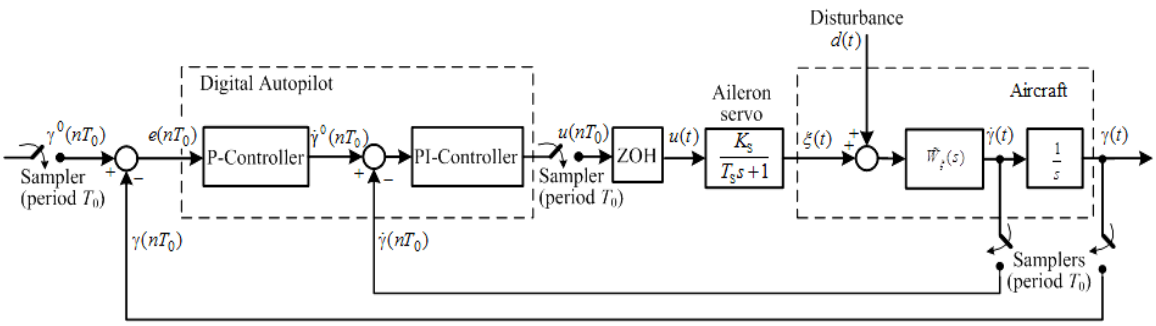

Fig. 1. Configuration of digital control system

The aim of the inner control loop exploiting the discrete-time PI control is to stabilize the roll rate $\dot{\gamma}(nT_0)$ at a given value, $\dot{\gamma}^0(nT_0)$, which is the output of the external control loop, as shown in Fig. 1. The feedback control law of this digital controller is

$$u(nT_0) = k_p^{\text{in}} e_{\dot{\gamma}}(nT_0) + k_i^{\text{in}} \sum_{i=0}^{n} e_{\dot{\gamma}}(iT_0), \tag{7}$$

where $e_{\dot{\gamma}}(nT_0)$, is the deflection of the true angular velocity, $\dot{\gamma}(nT_0)$, from a given angular velocity, $\dot{\gamma}^0(nT_0)$, at the time instant $t = nT_0$ given by

$$e_{\dot{\gamma}}(nT_0) = \dot{\gamma}^0(nT_0) - \dot{\gamma}(nT_0), \tag{8}$$

and k_P^{in} and k_I^{in} represent its parameters.

The sampled-data transfer function of the PI controller derived from (7) is determined as follows:

$$C^{\text{in}}(z) := \frac{U(z)}{E_{\dot{\gamma}}(z)} = k_P^{\text{in}} + \frac{k_I^{\text{in}} z}{z-1}, \tag{9}$$

where $U(z) := Z\{u(nT_0)\}$ and $E_{\dot{\gamma}} := Z\{e_{\dot{\gamma}}(nT_0)\}$ are the Z-transforms of $\{u(nT_0)\}$ and $e_{\dot{\gamma}}(nT_0)$, respectively.

The external feedback loop which contains the usual P controller is used to stabilize the roll angle, $\gamma(nT_0)$ around the desired value, $\gamma^0(nT_0)$ Its control law is defined by

$$\dot{\gamma}^0(nT_0) = k_P^{\text{ex}} e_{\gamma}(nT_0) \tag{10}$$

together with the output error

$$e(nT_0) = \gamma^0(nT_0) - \gamma(nT_0),$$

where $\gamma^0(nT_0)$ and $\gamma(nT_0)$ are a desired and true roll orientation at the time instant $t = nT_0$, respectively. Then the sampled-data transfer function corresponding to (10) will be determined as

$$C^{\text{ex}}(z) = k_{\text{P}}^{\text{ex}}. \quad (11)$$

B. Stability analysis

Inspecting Fig. 1 and recalling the notations (1), (2) and (9), one gets the discrete-time transfer function of inner feedback loop from $\dot{\gamma}^0$ to $\dot{\gamma}$ as

$$H^{\text{in}}(z) = \frac{C^{\text{in}}(z)W_{\text{S}}W_{\xi}(z)}{1 + C^{\text{in}}(z)W_{\text{S}}W_{\xi}(z)}, \quad (12)$$

where $W_{\text{S}}W_{\xi}(z) = (1 - z^{-1})Z\{L^{-1}\{W_{\text{S}}(s)W_{\xi}(s)\}_{t=nT_0}\}$ [14].

By applying the stability results with respect to the three-order control system which can be found in [15, subsect. 1.12], to the denominator of $H^{\text{in}}(z)$ in (12) we derive the conditions guaranteeing the stability of inner closed loop. It turned out that the set Ω^{in} of pairs $\left(k_{\text{P}}^{\text{in}}, k_{\text{I}}^{\text{in}}\right)$ under which the inner loop will be stable is bounded.

To study the stability of the external closed loop, we again inspect Fig. 1 to obtain the discrete-time transfer function of the corresponding open loop as

$$G(z) = k_{\text{P}}^{\text{ex}} G'(z), \quad (13)$$

where

$$G'(z) = \frac{W_{\text{S}}W_{\xi}W_0(z)}{1 + C^{\text{in}}(z)W_{\text{S}}W_{\xi}(z)}. \quad (14)$$

Applying the frequency stability criterion taken from [16] to (14) together with (15) we establish that the necessary and sufficient condition under which the closed loop will be stable is given by

$$0 < k_{\text{P}}^{\text{ex}} < -m, \quad (15)$$

where m is determined as

$$m = \min\{\operatorname{Re} G(e^{j\omega}) : \operatorname{Im} G(e^{j\omega}) = 0\}. \quad (16)$$

C. ℓ_1-Optimization

In order to choose the optimal parameters of both digital controllers, the ℓ_1-optimization approach is utilized. According to this approach we establish that

$$\limsup_{n\to\infty} |e_{\gamma}(nT_0)| \le \| H^{\text{ex}}(k_{\text{Ñ}}) \|_1 \| v^{\text{ex}} \|_{\infty} + O\left(\| \delta v \|_{\infty}\right) < \infty, \quad (17)$$

where

$$H^{\text{ex}}(z, k_{\text{C}}) = \frac{1}{1 + C^{\text{in}}(z)W_{\text{S}}W_{\xi}(z) + C^{\text{in}}(z)C^{\text{ex}}(z) + W_{\text{S}}W_{\xi}W_0(z)} \quad (18)$$

depends on the vector $k_{\text{C}} = [k_{\text{P}}^{\text{in}}, k_{\text{I}}^{\text{in}}, k_{\text{P}}^{\text{ex}}]^{\text{T}}$ of the controller parameters and $\| v^{\text{ex}} \|_{\infty}$ is the ∞-norm of $\{v^{\text{ex}}(nT_0)\}$ in which

$$v^{\text{ex}}(nT_0) = Z\left\{L^{-1}\left\{W_{\xi}(s)W_0(s)D(s)\right\}_{t=nT_0}\right\}$$

with $D(s) = L\{d(t)\}$. (Due to space limitation, details are omitted.)

According to (15), (16), the set Ω^{ex} of k_{P}^{ex}s guaranteeing the stability of the external loop for these k_{P}^{in}s and k_{I}^{in}s is bounded. Since Ω^{in} and Ω^{ex} are both bounded, it possible to utilize the well-known Weierstrass theorem [17, chap. 1, sect 3]. By virtue of this theorem, there exists some

$$k_{\text{C}}^* = \arg \min_{k_{\text{C}} \in \Omega^{\text{in}} \times \Omega^{\text{ex}}} \| H^{\text{ex}}(k_{\text{C}}) \|_1 . \quad (19)$$

minimizing ℓ_1-norm of the transfer function (18) in k_{C}.

Taking (17) into account, we see that the choice of k_{C}^* in accordance with (19) solves the ℓ_1-optimization problem formulated as the requirement (6). Unfortunately, the l_1-norm of $H^{\text{ex}}(z, k_{\text{C}})$ given by (26) is non-differentiable function with respect to the components $k_{\text{P}}^{\text{in}}, k_{\text{I}}^{\text{in}}, k_{\text{P}}^{\text{ex}}$ of k_{C}. Therefore, the random search technique taken from [17, chap. 6, item 4] is proposed to find the optimal parameter vector k_{C}^*, defined in (19).

IV. Robustness Evaluation

Let the nominal (approximate) transfer function $\tilde{W}_{\xi}(s)$ in (1) be

$$\tilde{W}_{\xi}(s) = \frac{10.84s}{0.4926s + 1}$$

that corresponds to the following parameters of an aircraft: $K_{\xi} = 10.84\ \text{s}^{-1}$ and $T_{\xi} = 0.4926\text{s}$ (as in [12, equation (3.62)]). According to [12, sect. 4.2] the transfer function of aileron servo is given by

$$W_{\text{S}}(s) = \frac{10}{s + 10}$$

that corresponds to $K_{\text{S}} = 1$, $T_{\text{S}} = 0.1\text{s}$ in (2). Put $T_0 = 0.01\text{s}$.

Exploiting the discrete time counterpart of the Routh–Hurwitz stability criterion to the denominator of (12) and also (15) together with (16), the bounded stability region representing the De Cartesian product $\Omega = \Omega^{\text{in}} \times \Omega^{\text{ex}}$ can be designed. It is the three-dimensional region covered by $\Omega_0 \supset \Omega$, where Ω_0 is an outer parallelepiped.

By using the random techniques of [17], the following vector of the ℓ_1-optimal controller parameters was found: $k_C^* = [4,\ 0.1,\ 3.9]^T$.

To study the robustness properties of this ℓ_1-optimal controller under the parametric uncertainty, we assumed that the parameters K_ξ and T_ξ are unknown but may vary within $\underline{K}_\xi \le K_\xi \le \overline{K}_\xi$ and $\underline{T}_\xi \le T_\xi \le \overline{T}_\xi$, where $\underline{K}_\xi = 8.672\ \text{s}^{-1}$, $\overline{K}_\xi = 12.47\ \text{s}^{-1}$ ($\underline{K}_\xi = 0.8K_\xi$, $\overline{K}_\xi = 1.15K_\xi$) and $\underline{T}_\xi = 0.468\ \text{s}$, $\overline{T}_\xi = 0.591\ \text{s}$ ($\underline{T}_\xi = 0.95T_\xi$, $\overline{T}_\xi = 1.2T_\xi$), respectively. The parametric uncertainty region corresponding to these ranges defined as $\Xi := [\underline{K}_\xi, \overline{K}_\xi] \times [\underline{T}_\xi, \overline{T}_\xi]$ is depicted in Fig. 2.

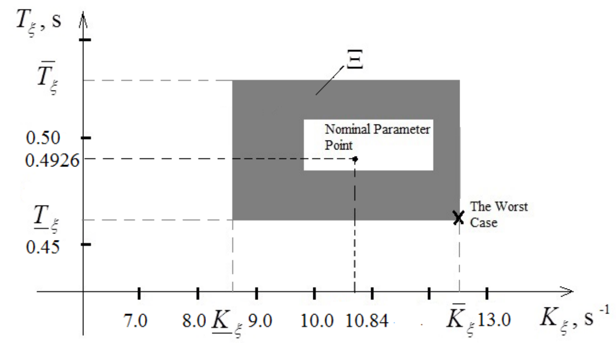

Fig. 2. Parameter uncertainty region

To evaluate the performance index of the control system containing the ℓ_1-optimal controller without and with uncertainties, two simulation experiments were conducted. In these experiments, variable $d(t)$ similar to the wind gust was simulated as Dryden Wind Turbulence Model.

It turned out that if the parametric uncertainty is present then the worst case (in the sense of robust stability) is: $K_\xi = \overline{K}_\xi$, $T_\xi = \underline{T}_\xi$ (see Fig. 2). Simulation results corresponding to the absence and the presence of this uncertainty are presented in Fig. 3.

To study the robustness properties of the ℓ_1-optimal controller under nonparametric uncertainty,

$$\tilde{W}_\xi(s) = \frac{0.171s(s+18.75)(s+0.15)}{(s^2+0.380s+1.813)(s+2.09)(s-0.004)}$$

taken from [12, equation 3.51) was set (instead of the previous $\tilde{W}_\xi(s)$). Simulation results corresponding to this case are given in Fig. 4.

Figures 3 and 4 show that the behavior of the ℓ_1-optimal control system in both situations is satisfactory.

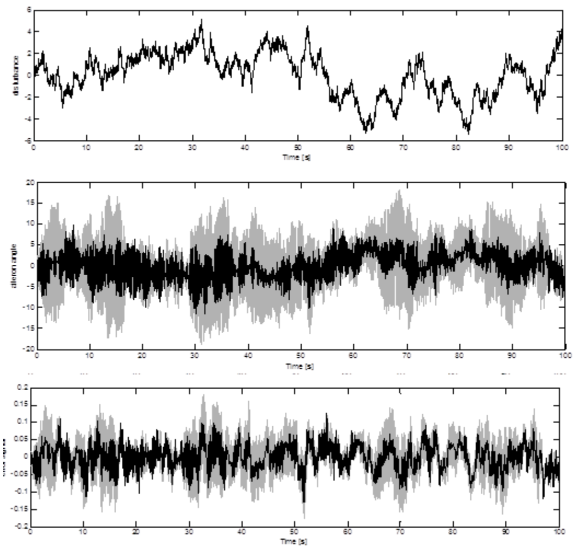

Fig. 3. Behavior of ℓ_1-optimal lateral autopilot without (black color) and with (gray color) parametric uncertainty

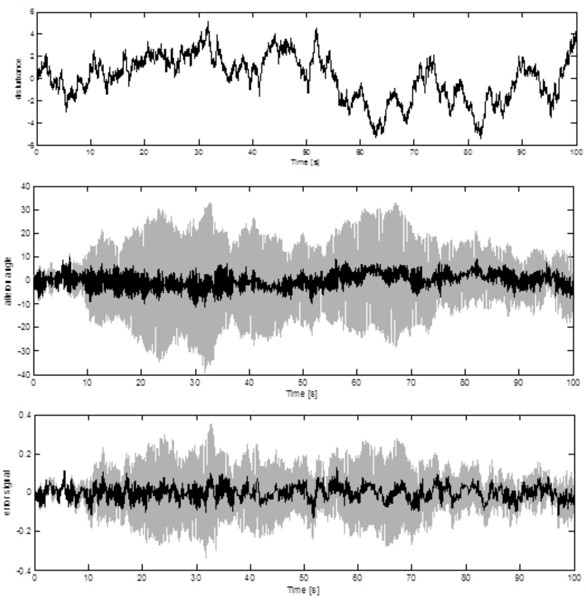

Fig. 4. Behavior of ℓ_1-optimal lateral autopilot without (black color) and with (gray color) nonparametric uncertainty

It follows from the results of [11] that the stability region Ω may be empty if the sampling period T_0 is sufficiently large. To verify this fact, we investigated the stability properties of the control system considered is simulation example for different values of T_0. Results of this investigation are presented in Fig. 5.

Figure 5 demonstrates that the simulated control system becomes unstable if T_0 exceeds the value equal to 0.0126 s whereas it remains stable for $T_0 < 0.0126$ s.

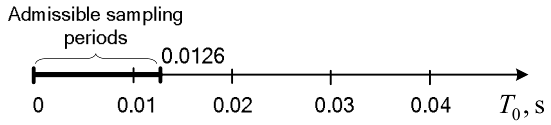

Fig. 5. Region of addmissible T_0s under which the autopilot system remains stable

V. CONCLUSION

The synthesis and analysis of a digital autopilot which is able to maintain a given roll orientation of an aircraft with a desired accuracy and to cope with an arbitrary external disturbance (a gust) were addressed in this paper. The digital autopilot was chosen as the ℓ_1-optimal controller containing the discrete-time PI and P controller parts.

It was established that the ℓ_1-optimal lateral autopilot may be robust in the presence both of parametric and of nonparametric uncertainties.

REFERENCES

[1] B. L. Stevens and F. L. Lewis, *Aircraft Control and Simulation*, 2nd ed., New York: John Willey & Sons, 2003.

[2] D. E. William, B. Friedland, and A. N. Madiwale, "Modern control theory for design of autopilots for bank-to-turn missiles," *J. Guidance Control*, vol. 10, pp. 378–386, 1987.

[3] E. K. Teoh, D. P. Mital, and K. S. Ang, "A BTT CLOS autopilot design," *The EEE Journal*, vol. 4, pp. 1–7, 1992.

[4] K. S. Ang, E. K. Teoh, and D. P. Mital, "Adaptive control of a missile autopilot system," in *Proc. 12th IFAC World Congress*, vol. 1, pp. 293–296, 1993.

[5] S. M. B. Malaek, H. Izadi, and M. Pakmehr, "Intelligent Autolanding Controller Based on Neural Net works," in *Proc. 1st African Control Conference* (AFCON2003), Cape Town, South Africa, vol. 1, pp. 113–119, 2003.

[6] M. R. Khrosravani, "Application of neural network on flight control," *Int. Journal of Machine Learning and Computing*, vol. 6, pp. 882–885, 2012.

[7] E. Lavretsky, and K. A. Wise, *Robust and Adaptive Control with Aerospace Application*. London: Springer-Verlag. 2013.

[8] M. A. Dahleh and J. B. Pearson, "l_1-optimal feedback controllers for discrete-time systems," in *Proc. American Control Conference*, Seattle, WA, pp. 1964–1968, 1986.

[9] M. Vidyasagar, "Optimal rejection of persistent bounded disturbances," *IEEE Trans. on Autom. Control*. vol. 31, pp. 527–534, 1986.

[10] M. H. Khammash, "A new approach to the solution of the l_1 control problem: the scaled-Q method," *IEEE Trans. on Autom. Control*, vol. 45, pp. 180–187, 2000.

[11] K. V. Melnyk, L. S. Zhiteckii, A. M. Bogatyrov, and A. Yu. Pilchevsky, "Digital control of lateral autopilot system applied to an UAV: optimal control strategy," in *Proc. 2013 2nd IEEE Int. Conf. "Actual Problems of Unmanned Air Vehicles Developments*," Oct., 15-17, Kiev, Ukraine, pp. 189–192, 2013.

[12] J. H. Blakelock, *Automatic Control of Aircraft and Missiles*, 2nd ed., New York: John Wiley & Sons, Inc., 1991.

[13] J. I. Yuz and G. C. Goodwin, *Sampled-Data Models for Linear and Nonlinear System*. London: Springer-Verlag. 2014.

[14] J. T. Tou, *Digital and Sampled-Data Control Systems*, New York: McGraw-Hill Book Company, 1959.

[15] E. I. Jury, *Sampled-Data Conrol Systems*, New York: John Willey & Sons Inc., 1958.

[16] B. T. Polyak and P. S. Shcherbakov, *Robust Stability and Control*, Moscow: Nauka, 2002 (in Russian).

[17] B. T. Polyak, *Introduction to Optimization*, New York: Optimization Software Inc., 1987.

Received June 11, 2016

Azarskov Valerii. Doctor of Engineering. Professor. Head of a Department.
Aircraft Control Systems Department, National Aviation University, Kyiv, Ukraine.
Education: Kyiv Civil Aviation Engineers Institute, Kyiv, Ukraine, (1968).
Research interests: control systems for aviation and space objects.
Publications: 250.
E-mail: azarskov@nau.edu.ua

Zhiteckii Leonid. Candidate of Engineering. Professor.
Division of the Automated Systems for Data Processing, Int. Centre of Int. Tech. & Syst., Kyiv, Ukraine.
Education: Odessa Polytechnic Institute, Odessa, Ukraine, (1962).
Research interests: control theory and its application.
Publications: over 200.
E-mail: leonid_zhiteckii@i.ua

Pilchevsky Andriy. Postgraduate student.
Division of the Automated Systems for Data Processing, Int. Centre of Int. Tech. & Syst., Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2015).
Research interests: aircraft control systems.
Publications: 7.
E-mail: terosjj@gmail.com

Solovchuk Klavdiia. Postgraduate student.
Division of the Automated Systems for Data Processing, Int. Centre of Int. Tech. & Syst., Kyiv, Ukraine.
Education: Poltava National University, Poltava, Ukraine, (2009).
Research interests: control systems.
Publications: 14.
E-mail: solovchuk_ok@mail.ru

В. М. Азарсков, Л. С. Житецький, А. Ю. Пільчевський, К. Ю. Соловчук. Робастні властивості ℓ_1-оптімального автопілоту бічного руху ПІ-типу

Розглянуто задачу побудови ℓ_1-оптімального цифрового автопілоту, необхідного для керування креном деякого літального апарату за наявності довільних невимірювальних збурень. Автопілот має забезпечувати бажане керування бічним рухом шляхом мінімізації верхньої межі абсолютного значення різниці між заданим й істинним кутом крену. Це здійснюється двома цифровими ℓ_1-оптімальними регуляторами ПІ-типу. Головний результат полягає у встановленні того факту, що автопілот може бути робастним за наявності параметричних і непараметричних невизначеностей.
Ключові слова: літальний апарат; динаміка бічного руху; цифрова система керування; дискретній час; стійкість; ℓ_1-оптімізація; робастність.

Азарсков Валерій Миколайович. Доктор технічних наук. Професор. Завідувач кафедрою.
Кафедра систем управління літальних апаратів, Національний авіаційний університет, Київ, Україна.
Освіта: Київський інститут інженерів цивільної авіації, Київ, Україна, (1968).
Напрям наукової діяльності: системи керування авіаційними і космічними об'єктами.
Кількість публікацій: 250.
E-mail: azarskov@nau.edu.ua

Житецький Леонід Сергійович. Кандидат технічних наук. Професор.
Відділ автоматизованих систем обробки даних, Міжнародний науково-навчальний центр інформаційних технологій і систем НАН України і МОН України, Київ, Україна.
Освіта: Одеський політехнічний інститут, Одеса, Україна, (1962).
Напрям наукової діяльності: теорія керування та її застосування.
Кількість публікацій: понад 200.
E-mail: leonid_zhiteckii@i.ua

Пільчевський Андрій Юрійович. Аспірант.
Відділ автоматизованих систем обробки даних, Міжнародний науково-навчальний центр інформаційних технологій і систем НАН України і МОН України, Київ, Україна
Освіта: Національний авіаційний університет, Київ, Україна, (2015).
Напрям наукової діяльності: системи керування літальними апаратами.
Кількість публікацій: 7.
E-mail: terosjj@gmail.com

Соловчук Клавдія Юріївна. Аспірант.
Відділ автоматизованих систем обробки даних, Міжнародний науково-навчальний центр інформаційних технологій і систем НАН України і МОН України, Київ, Україна.
Освіта: Полтавський національний університет, Полтава, Україна, (2009).
Напрям наукової діяльності: системи керування.
Кількість публікацій: 14.
E-mail: solovchuk_ok@mail.ru

В. Н. Азарсков, Л. С. Житецкий, А. Ю. Пильчевский, К. Ю. Соловчук. **Свойства робастности ℓ_1-оптимального автопилота бокового движения ПИ-типа**

Рассмотрена задача построения ℓ_1-оптимального цифрового автопилота, необходимого для управления креном некоторого летального аппарата при произвольных неизмеряемых возмущениях. Автопилот должен обеспечивать желаемое управление боковым движением путем минимизации верхней границы абсолютного значения разности между заданным и истинным углом крена. Это осуществляется двумя цифровыми ℓ_1-оптимальными регуляторами ПИ-типа. Главный результат заключается в установлении того факта, что автопилот может быть робастным при наличии параметрических и непараметрических неопределенностей.
Ключевые слова: летательный аппарат, динамика бокового движения, цифровая система управления, дискретное время, устойчивость, ℓ_1-оптимизация, робастность.

Азарсков Валерий Николаевич. Доктор технических наук. Профессор. Заведующий кафедрой.
Кафедра систем управления летательных аппаратов, Национальный авиационный университет, Киев, Украина.
Образование: Киевский институт инженеров гражданской авиации, Киев, Украина, (1968).
Направление научной деятельности: системы управления авиационными и космическими объектами.
Количество публикаций: 250.
E-mail: azarskov@nau.edu.ua

Житецкий Леонид Сергеевич. Кандидат технических наук. Профессор.
Отдел автоматизированных систем обработки данных, Международный научно-учебный центр информационных технологий и систем НАН Украины и МОН Украины, Киев, Украина.
Образование: Одесский политехнический институт, Одесса, Украина, (1962).
Направление научной деятельности: теория управления и ее приложение.
Количество публикаций: свыше 200.
E-mail: leonid_zhiteckii@i.ua

Пильчевский Андрей Юрьевич. Аспирант.
Отдел автоматизированных систем обработки данных, Международный научно-учебный центр информационных технологий и систем НАН Украины и МОН Украины, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина, (2015).
Направление научной деятельности: системы управления летательными аппаратами.
Количество публикаций: 7.
E-mail: terosjj@gmail.com

Соловчук Клавдия Юрьевна. Аспирант.
Отдел автоматизированных систем обработки данных, Международный научно-учебный центр информационных технологий и систем НАН Украины и МОН Украины, Киев, Украина.
Образование: Полтавский национальный университет, Полтава, Украина, (2009).
Направление научной деятельности: системы управления.
Количество публикаций: 14.
E-mail: solovchuk_ok@mail.ru