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SYNTHESIS OF OPTIMAL FILTER OF AUTOMATED CONTROL SYSTEM OF SELF-AIMING UNMANNED AIR VEHICLE WITH FIXED COORDINATOR

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Abstract

A structured schema is synthesized and a preliminary function of the the optimal filter of the control system of the self-aiming unmanned air vehicle (UAV) with fixed coordinator using some statisitical methods was obtained .

The conducted investigations showed that if the UAV itself is included in the control system the analysis of the aimed circle will be significantly relieved, as the control system of the UAV with fixed coordinator can be regarded as a following system.

Introduction

In a number of leading in martial relation countries a deep transformation of the armed forces is done in order to adapt them to the threats and the challenges in the new information century. It is in close contact to the new military strategy, which infers that the contemporary war should be conducted in short term and with minimal losses via delivering highly precise strikes from air-space or water-space without immediate contact with the opponent. This approach is known as “distant (non-contact) war”. It becomes possible due to the successful development of new armaments specimen and military techniques which have: improved concealment and safety, global reconnaissance and surveillance systems, navigation and target indication, highly precise striking means and control systems, built on network principal integrated in common reconnaissance-striking (information-striking) systems.

The distant war determines principally new requirements towards the providing to the armies and forces with contemporary armaments and techniques, including highly effective control, reconnaissance and communication systems.

In this regard great attention has been brought to the development of the aero-space component of the armed forces as well as the concept of its use. As plans up to 2020 for development of the military forces of the NATO member countries show, one of the main streams of the MAF (military air force) development is elaboration and acceptance of armaments of unmanned aviation complexes and systems with diverse purpose (including reconnaissance-striking unmanned complexes and their control systems) [2, 4].

In the late sixties in Republic of Bulgaria begins the development of unmanned air vehicle (UAV) of type radio-manipulated targets. On a later stage the development of reconnaissance UAV steps in and it continues up to these days. In certain circumstances the reconnaissance UAV can be transformed into reconnaissance – striking ones. Therefore the investigation and the synthesis of their control systems and their elements is a key phase of their development.

As pointed in [7, 8] for hitting enemy targets with reconnaissance – striking UAV it is essential that the information received by the television or infrared camera installed on the UAV’s board to be real-time, in order to adjust its position according to the longitudinal axis of the UAV from 0 to 90 degrees. This information is monitored on a screen by an operator in a land control station. Target-lightening systems are used for improving visibility of targets.

When the operator discovers enemy target in the received TV image, they aim the unmanned air vehicle toward it. In this way the control system (CS) of the UAV starts receiving and processing the signal reflected by the target. In case of high enough amplitude of the accepted information signal the CS starts navigating the UAV autonomously until hitting the target.

At the combat UAV, that reaches the target using controlled and uncontrolled rockets or through straight shot in it (kamikaze type) standing coordinator could be used, which longitudinal axes coincides with the longitudinal axes of the unmanned air vehicle. That allows straight-direction methods where the UAV long axes are directed to the target during the whole flight to be used.

In this case UAV control system could be analyzed as system consisting of coordinator, which measures the target angle position according to the UAV long axes and unmanned vehicle, which eliminates that angle of non-coherence, trying to keep it zero [5].

Optimum Control System

CS should be optimal to be able to define the co-ordinates of the target with minimal possible mistake [7]. During the design and synthesis of the CS usually is needed that UAV characteristics, enemies' targets, informational signals and possible interferences are defined. The structure and scales of CS are defined according to those characteristics. The size of the linear diversion of UAV from the target center is defined as well at the moment when the unmanned vehicle hits the area, which is perpendicular of its flight path and consists as a spot the target center.

In practice, however, there is never a whole set of needed information but only some statistic characteristics. That's why the synthesized CS should be able to change its parameters depending on the conditions of using the UAV, so that its accuracy in general to be equal of the maximum possible for the particular situation.

Due to that above during the design of the optimum CS of self-aiming UAV with fixed coordinator, statistic methods are most reasonable to be used – such as the method of the maximum aposterior possibility and the method of maximum function of probability [1].

In the case above the measured target angle depends on many accidental factors such as: direction, maneuvers, target and UAV autowaverings, UAV target accuracy in the moment of attack, turbulence, etc. All those factors are accidental and their influence over the stochastic process leads to its usual distribution. That's why can be accepted that the measured angle of the attacked target $\lambda(t)$ is commonly distributed.

When the method of maximum aposterior possibility is used the measured parameter value (the angle co-ordinate of the attacked target) is worth due to chosen values of the entering realizations of the received information signal. Therefore for optimal valuation of the unknown parameter (the measured angle) λ is taken the value λ_{exit}, where the aposterior possibility $P_{ps}(\lambda)$ has its maximum.

When the method of maximum aposterior possibility is used a block-diagram of the optimal coordinator is synthesized (coordinator measurement) such as the one shown at fig. 1 [7].

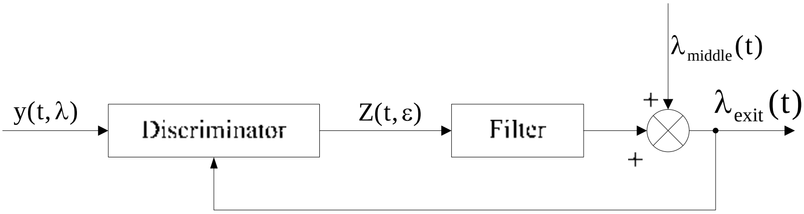

Fig. 1. Block-diagram of optimal coordinator measurer

The received informational signal is processed in the discriminator. Due to that at its exit voltage Z(t,ε) appears which is proportionally equal to the non-coherence. It comes at the entrance of the filer, which impulse-transitional function is equal to $C^{-1}(t,\tau)$. At the exit filter signal should add middle quantity of the measured angle $\lambda_{middle}(t)$, and in result of it its optimal value is created $\lambda_{exit}(t)$. To have the diagram of the measurement followed, this optimal value needs to be clarified, i.e. $\lambda_{exit}(t)$ to be proceeded by the discriminator.

The aim of the coordinator is to keep the angle of non-coherence about to zero, i.e. to keep tight the axis of the diagram of the orientation of the optical system, which receives the informational signal together with target direction.

During the synthesis of the optimal coordinator according to the set characteristics of the informational signal y(t), the measured angle λ(t) and sound n(t) need to be found optimal structural diagrams of the: discriminator, measurement of the optimal steepness of the pelengation characteristics and filter.

Optimal discriminator structure is defined in [5] as the method of the function probability maximum is used, where the probability equation is worked out. [1]:

(1) $$\frac{\partial \ln P[y(t),\varepsilon]}{\partial \lambda(t)} = 0,$$

where P[y(t),ε] – probability function; $\varepsilon = \lambda - \lambda_{exit}$ – target angle diversion of the flat signal discriminatory zone (angle of non-coherence); $\lambda_{exit}(t)$ – angle measured value (value of the measured angle).

The probability function is defined by the functional of the density distribution of the probability of the registered signal P[y(t)], which is regarded as function of the parameter of the non-coherence ε.

The structural schema of the measurer of the optimal steep of the pelengation characteristic is defined as the second derivative of the probability function [1, 6]:

$$A_{ij} = -\frac{\partial^2 \ln P[y(t), \varepsilon]}{\partial \varepsilon_i \partial \varepsilon_j}, \tag{2}$$

where **$A_{i,j}$ –** is matrix, characterizing the optimal steep of the pelengation characteristic; i,j = 1,2, ... , n; **y**(t) = $y_1(t)$, $y_2(t)$, ...$y_n(t)$ – row vector of the received realization; **ε =** ε_1, ε_2, ... ,ε_n **–** column vector of the measurement non-coherency.

Synthesis of the Optimal Filter

A few methods can be used for defining the structure of the optimal filter, on whose output should be received the optimal value of the measured angle: the method of the minimum square quadratic deviation; the method of non-linear filtration; the method of the maximum of the aposterior probability, etc. In the latter, an integral equation is drawn, which defines the optimum impulse transition function of the filter:

$$C^{-1}(t,\tau) + \int_{t_0}^{t} C^{-1}(s,\tau) A(s) R(s,\tau) ds = R(t,\tau) \ , \tag{3}$$

where $A(s)$ is the optimal steep of the pelengation characteristic of the discriminator; $R(t,\tau)$ - correlation function of the information signal**.**

In its general form the equation is hard to solve without specifying the correlation function of the information function and the optimal steep of the pelengation characteristic of the discriminator. Therefore it is necessary to describe them with statements corresponding to their physical nature.

From experience we know that the measured angle λ(t) is static accidental process, whose correlation function depends on the difference of its arguments, i.e. has the form R(t-τ). In this case the correlation coefficient r(t-τ) is experimentally determined and from the received graphic is chosen the empiric formula which can describe it.

For most of the coordinate's measurers the empiric formula of the correlation coefficient can be presented as [3]:

(4) $$r(t-\tau) = e^{-36(t-\tau)}\cos 43(t-\tau) .$$

If taken into consideration that in small values of the time interval (t-τ) the function cos43(t-τ) ≈ 1, then the correlation coefficient will be equal to:

(5) $$r(t-\tau) = e^{-36(t-\tau)} .$$

Then the correlation function which corresponds to such correlation coefficient will be equal to:

(6) $$R(t-\tau) = Be^{-\beta(t-\tau)} ,$$

where $\beta = 36$ and the value of B is defined by the type of the input information signal.

The function A(t) is a variable stochastic function, characterizing the steep of the pelengation characteristic of the discriminator. It has positive mathematical expectancy (ratio) and changes significantly slower than the correlation function R(t-τ).

Therefore the integral equation, defining the impulse transition function of the filter can be described as:

(7) $$C^{-1}(t,\tau) + \int_{t_0}^{t} C^{-1}(t,\tau)A(s)R(t-s)ds = R(t-\tau) ,$$

i.e. it is transformed into integral equation with different-sided core. If we introduce the designation $C^{-1}(t,\tau) = g(t,\tau)$ and take into account the slow alteration of A(t), then formula (6) will look like:

(8) $$g(t,\tau) + A(t)\int_{t_0}^{t} g(t,s)R(t-s)ds = R(t-\tau) .$$

The simplest way of solving such integral equations is the method of consecutive approximation, i.e.

(9) $$g(t,\tau) = g_0(t,\tau) - g_1(t,\tau)A(t) + g_2(t,\tau)A^2(t) - ......,$$

where:

(10) $$g_0(t,\tau) = R(t-\tau),$$

(11) $$g_1(t,\tau) = \int_{t_0}^{t} g_0(t,\tau)R(t-\tau)d\tau,$$

(12) $$g_n(t,\tau) = \int_{t_0}^{t} g_{n-1}(t,\tau)R(t-\tau)d\tau.$$

Then the first article of the row will be:

(13) $$g_0(t,\tau) = Be^{-\beta(t-\tau)},$$

the second article:

(14) $$g_1(t,\tau) = \int_{t_0}^{t} Be^{-\beta(t-\tau)}R(t,\tau)d\tau = \frac{B^2}{2\beta}\left[1 - e^{-2\beta(t-t_0)}\right],$$

the third article:

(15) $$g_2(t,\tau) = \frac{B^3}{2\beta^2}\left[1 - e^{-2\beta(t-t_0)}\right]\left[1 - e^{-\beta(t-t_0)}\right]$$

and the fourth article:

(16) $$g_3(t,\tau) = \frac{B^4}{2\beta^3}\left[1 - e^{-2\beta(t-t_0)}\right]\left[1 - e^{-\beta(t-t_0)}\right]^2.$$

The common article of the row can be written in the following appearance, taking into account formulas from (13) to (16):

(17) $$g_n(t,\tau) = \frac{B^{n+1}}{2\beta^n}\left[1 - e^{-2\beta(t-t_0)}\right]\left[1 - e^{-\beta(t-t_0)}\right]^{n-1}.$$

Thus the row which is the solution to the integral equation will have the look:

(18)

$$g(t,\tau) = Be^{-\beta(t-\tau)} - A(t)\frac{B^2}{2\beta}\left[1 - e^{-2\beta(t-t_0)}\right] + A^2(t)\frac{B^3}{2\beta^2}\left[1 - e^{-2\beta(t-t_0)}\right]\left[1 - e^{-\beta(t-t_0)}\right] - \ldots$$

$$\ldots..(-1)^{n-1}A^n(t)\frac{B^{n+1}}{2\beta^n}\left[1 - e^{-2\beta(t-t_0)}\right]\left[1 - e^{-\beta(t-t_0)}\right]^{n-1}.$$

Equation (18) shows that the impulse transition function of the optimal filter, evening the measured value of the angle of optimal coordinator, is presented in the form of an endless row. From practical consideration this entry can be significantly simplified by taking into account the following facts:

- every following article in the row is β times less then the preceding one;
- 1- $e^{-\beta(t-\tau)} < 1$;
- with increasing the number of articles in the row (its promotion to a degree) it becomes much smaller than one.

Therefore, with the needed in practice precision the row may be restricted to just the first two – three articles. Then the impulse transiting function of the filter can be noted as:

(19)

$$g(t,\tau) = Be^{-\beta(t-\tau)} - A(t)\frac{B^2}{2\beta}\left[1 - e^{-2\beta(t-t_0)}\right] \quad x$$

$$x\left\{1 - \frac{A(t)B}{\beta}\left[1 - e^{-\beta(t-t_0)}\right]\right\}.$$

Equation (19) can be simplified by accepting $t_0 = 0$. This acceptance is true for all short-term memory systems (systems, which return to their initial state shortly after their reaction to external interference). It can be extended to the remaining systems, if taking into account that t_0 represents a fixed moment of time, close to the moment of aiming of the UAV to the target, and t is the current time moment, which grows fast. In this case $t - t_0 \to t$. When the UAV approaches the target (it is needed to have the highest precision for measuring its coordinates at that moment), we can consider that $t - t_0 = t$. Thus the impulse transition function takes its final form:

$$g(t,\tau) = Be^{-\beta(t-\tau)} - A(t)\frac{B^2}{2\beta}(1-e^{-2\beta t}) \quad x \tag{20}$$
$$x \left[1 - \frac{A(t)B}{\beta}(1-e^{-\beta t})\right].$$

If we sign:

$$\frac{B^2}{2\beta}(1-e^{-2\beta t})\left[1 - \frac{A(t)B}{\beta}(1-e^{-\beta t})\right] = Д(t), \tag{21}$$

then instead (20) for the impulse transition function we have:

$$g(t,\tau) = Be^{-\beta(t-\tau)} - A(t)Д(t) \quad . \tag{22}$$

Using the deducted above formula (22) for the impulse transition function of the filter, can be synthesized the structural schema of the optimal filter of coordinator, whose transmission function is equal to:

$$G(p) = \int_0^s g(t,\tau)e^{-p\tau}d\tau \, . \tag{23}$$

After replacing of (22) in (23) we have:

$$G(p) = \left[\frac{A(t)Д(t)}{p} - \frac{B}{p-\beta}e^{-\beta(t-s)}\right]e^{-ps} \, . \tag{24}$$

If we sign T = - 1/β, then instead of (24) we have the following transmission function of the optimal filter:

$$G(p) = \left[\frac{A(t)Д(t)}{p} - \frac{TB}{Tp+1}e^{(t-s)/T}\right]e^{-ps} \, . \tag{25}$$

Using the deducted transmission function (25) the following structural schema of the optimal filter, shown in fig.2 can be composed:

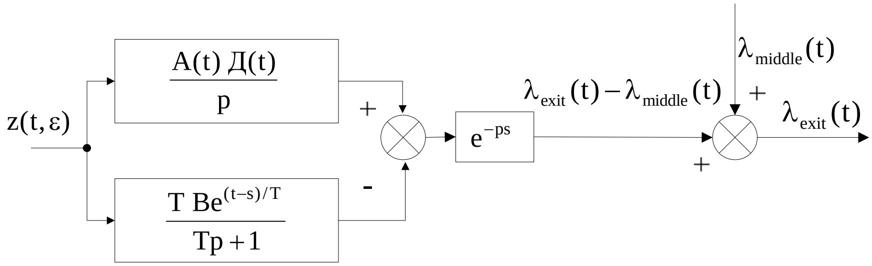

Fig. 2. Optimal filter of coordinator

From it is visible that in order to achieve optimal estimation (value) of the measured angle, the output signal of the optimal discriminator must be let through optimal filter, which consists of the following units: integrating unit with variable magnifying coefficient, proportional to the optimal steep of the pelengation characteristic of the discriminator and dependant on the parameters of the correlation function of the input signal; integrating unit with variable magnifying coefficient, determined by the parameters of the correlation function and unit with constant delay of time s, equal to the time for which the impulse transition function $g(t,\tau) > 0$.

Conclusion

At first glance the above described structural schema of the optimal filter looks hard to put in practice as the ratio of the measured angle - $\lambda_{middle}(t)$ should be added to the output signal of the filter (executive organs of the UAV and the UAV itself). Actually, it only relieves the technical realization as the axis of the UAV with fixed coordinator during the flight is aimed at the target and its orientation in space is the same as the direction of the ratio of the measured angle. Thus the UAV works off only the appearing deviations from this angle.

The deducted structural schema of the optimal filter shows that if the UAV itself is included in the control system, then the analysis of the aiming circle of the UAV can be relieved significantly, as the control system of UAV with fixed coordinator can be regarded as following system.

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СИНТЕЗИРАНЕ НА ОПТИМАЛЕН ФИЛТЪР ОТ СИСТЕМАТА ЗА УПРАВЛЕНИЕ НА САМОНАСОЧВАЩ СЕ БЕЗПИЛОТЕН ЛЕТАТЕЛЕН АПАРАТ С НЕПОДВИЖЕН КООРДИНАТОР

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Резюме

Синтезирана е структурната схема и е получена предавателната функция на оптимален филтър от системата за управление на самонасочващ се безпилотен летателен апарат с неподвижен координатор като са използвани някои статистически методи.

Проведеното изследване показва, че ако към системата за управление се включи и самият БЛА, то анализът на кръга на насочване на БЛА към целта може да се облекчи съществено, тъй като системата за управление на БЛА с неподвижен координатор може да бъде разглеждана като следяща система.