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DESIGN OF THE CONTROL SYSTEM FOR THE UNMANNED AERIAL VEHICLE BY MATLAB SYSTEM

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Abstract

The necessity of research and evaluation of the influence of rudder and aileron deflection on the UAV performance is substantiated. It is shown that in the absence of a regulator, periodic oscillations of the yaw occur, sometimes reaching several tens of degrees. A washout filter based on a new method has been developed to improve the performance and flight modes of the UAV.

Key words: control system, UAV, linear time-invariant, rudder, aileron, impulse, root locus, washout filter, damping ratio.

Introduction

A distinctive feature of unmanned aerial vehicles (UAV) is the absence of a pilot on board [1]. The flight of the UAV can operate with varying degrees of autonomy: using a remote control device; using the automatic piloting system which functions both on the device itself and on the flight monitoring and control device. Compared to manned aircraft, UAV are designed to carry out missions that pose a significant danger to people, as well as missions that have an unjustified large expenditure of resources to perform primitive actions. Appropriate software can be installed in the UAV to perform various tasks offline, that is, without human intervention.

Initially, UAV were created primarily for military purposes, but with the development of technology, UAV have found their application in civilian areas (patrol and surveillance, delivery of goods, aerial photography, video filming, agriculture, etc.). Now an important task is to design an accurate microprocessor system for controlling the UAV.

The purpose of this work is to develop a microprocessor control system for motion analysis, improving the characteristics and reliability of the UAV.

Conflict setting

This paper demonstrates the tools for designing a control system by step-by-step describing the design of a yaw damper for an UAV.

Several aerodynamic forces act on an UAV in level flight, which compensate each other: gravity F_g, wing lift F_l, engine thrust force F_t, air resistance force F_d, stabilizer force F_s compensating the longitudinal moment if the points of application of gravity and lift do not match. The forces acting on the UAV are recalculated and reduced to one point, but due to the fact that in reality the points of application of these forces are different, torques are used [1].

Driving torques rotate the UAV around the axes, just as forces displace the plane along the axes. In total, the UAV has 6 degrees of freedom, movement along the coordinates of the X, Y, Z rectangular axes and rotation around the X, Y, Z axes (Fig. 1). In the MATLAB system for UAV modeling, the Structural Frame coordinate system is used. The X axis in this coordinate system is directed against the movement of the model, the Y axis is to the right along the wing, and the Z axis is directed upward along the symmetry axis in the vertical plane. Drag, side, lift - these are the forces that shift the center of gravity of the model along the corresponding axes. Roll, pitch, yaw - are the torques that rotate the model around the corresponding axis passing through the center of gravity.

At a flight speed 1.25 times less than the speed of sound, at an altitude of 4,000 m, the UAV is given by the description in the state space [2]:

$$X = AX + BU\dot{,} Y = CX + DU$$

$$A = \begin{pmatrix} -0.0643 & -0.8876 & 0.0701 & 0.0324 \\ 0.4860 & -0.2330 & -0.0216 & 0 \\ -2.8900 & 0.3660 & -0.3740 & 0 \\ 0 & 0.0602 & 1.0000 & 0 \end{pmatrix}, \; B = \begin{pmatrix} 0.0618 & 0 \\ -4.6400 & 0.0066 \\ 5.1320 & 0.1210 \\ 0 & 0 \end{pmatrix}$$

$$C = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \; D = \begin{pmatrix} 0 & 0 \\ 0 & 0 \end{pmatrix}$$

where $X \in R^4$ - state vector, U,Y - vectors of input and output signals.

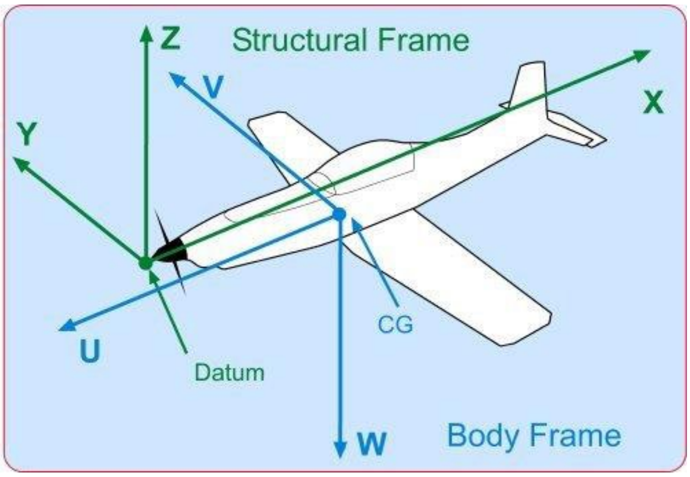

Fig. 1 Coordinate systems and their reference points

The following commands define this state-space model as a linear time-invariant (LTI) system and assign names to the states, inputs, and outputs

```
>> states = {'beta' 'yaw' 'roll' 'phi'};
>> inputs = {'rudder' 'aileron'};
>> outputs = {'yaw' 'bank angle'};
>> sys = ss (A,B,C,D,'statename',states,...
'inputname',inputs,...
'outputname',outputs);
```

The model has two inputs and two outputs. The units are radians for β (side slip angle) and φ (roll angle) and newton per meter for yaw and roll. Rudder and aileron deflections are also given in radians.

Calculation of the eigenvalues of an open system is carried out using the damp function.

```
>> damp(sys)

   Eigenvalue                 Damping      Freq. (rad/s)

 -7.28e-003                   1.00e+000     7.28e-003
 -5.63e-001                   1.00e+000     5.63e-001
 -3.29e-002 + 9.47e-001i      3.48e-002    9.47e-001
 -3.29e-002 - 9.47e-001i      3.48e-002    9.47e-001
```

The location of zeros and poles in the complex plane can be obtained by typing the *pzmap (sys)* command with no output argument.

This model has one pair of lightly damped poles. They correspond to the so-called “Dutch rolling regime” [1]. It is necessary to design a compensator that increases the damping of these poles so that the resulting complex poles have a damping coefficient $\zeta>0.35$ with a natural frequency $\omega_n < 1$rad/s. This can be done using the analysis tools of the Control System toolbar.

Open system analysis

We shall now derive some open-loop analysis to determine possible control strategies. To simulate the UAV, an impulse function is used, which is the response of the system to the input signal in the form of a delta function [3]. Graphs of the impulse function have been studied, which make it possible to determine the regulation law (Fig. 2). The impulse response confirms that the system is slightly damped.

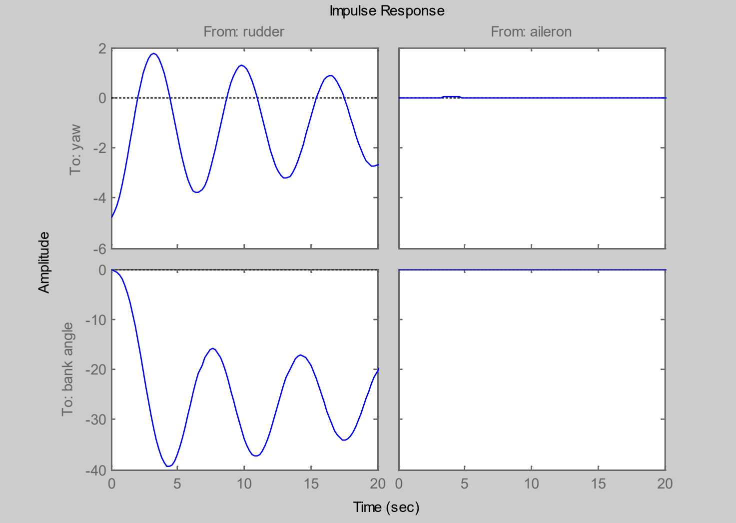

Fig. 2 Graphs of the impulse function for an open system on the interval 0≤t≤20

Of great interest is the graph from aileron deflection (input 2) to bank angle (output 2). To display only this graph, you must right-click and select I/O Selector, then click on entry (2,2). The resulting new graph is shown in Fig. 3.

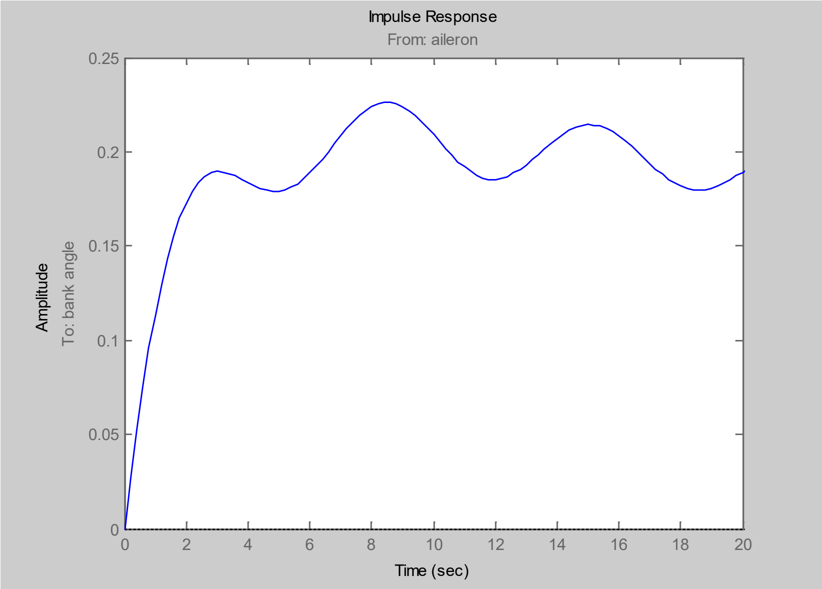

Fig. 3 Graph of the impulse response for an open system from input 2 (aileron deflection) to output 2 (roll angle)

The UAV oscillates around a non-zero bank angle. Thus, the UAV turns in response to the aileron impulse. This behavior will prove to be an important point in the analysis of UAV movement.

The root locus method

The design goal is to provide a damping coefficient ζ>0.35 with natural frequency $\omega_n < 1.0$ rad/s. Since the simplest compensator is the static gain, we first try to determine the appropriate gain values using the root locus method. UAV parameters can be displayed by command:

```
>> rlocus(sys11)
```

This is a root locus with negative feedback, which shows that the system becomes unstable almost immediately [4]. If we use a positive feedback system instead, we can get a stable system with the following command (Fig. 4):

```
>> rlocus(-sys11)
>> sgrid
```

Using simple feedback, a damping coefficient of ζ=0.45 can be achieved. To do this, click on the top curve and move the data marker to track the gain and damping coefficient. To achieve a damping coefficient of 0.45, the gain should be around 2.85. The creation of a closed linear system with the specified gain is carried out by the command:

```
>> K = 2.85;
>> cl11 = feedback (sys11, -K);
```

The output of the graph of the impulse response of a closed system with a given range of values along the abscissa axis and its comparison with the graph of the impulse response of an open system is performed using the function:

```
>> impulse (sys11,'b--’, cl11,'r',20)
```

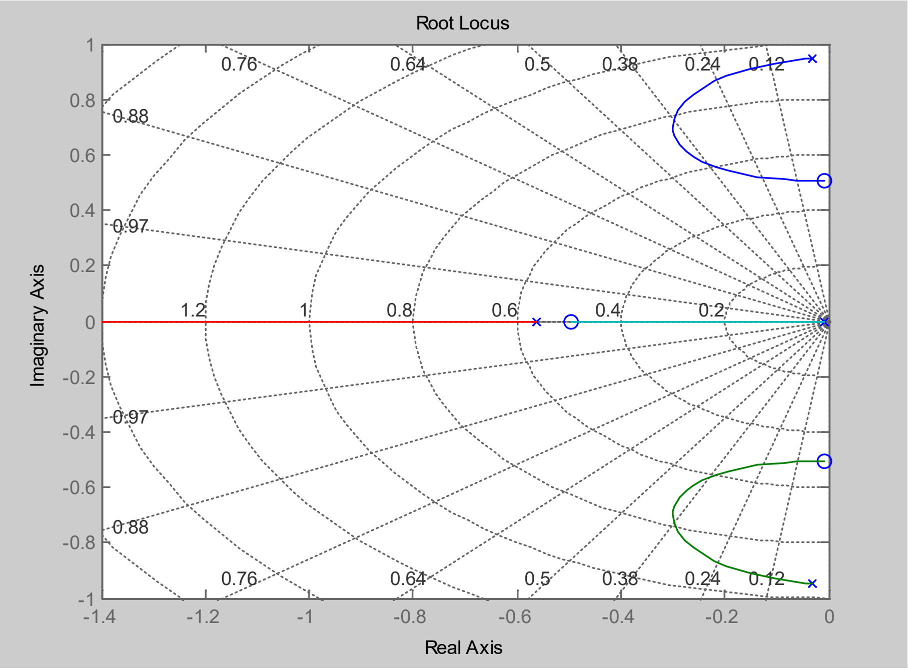

Fig. 4 Root locus of a system with positive feedback

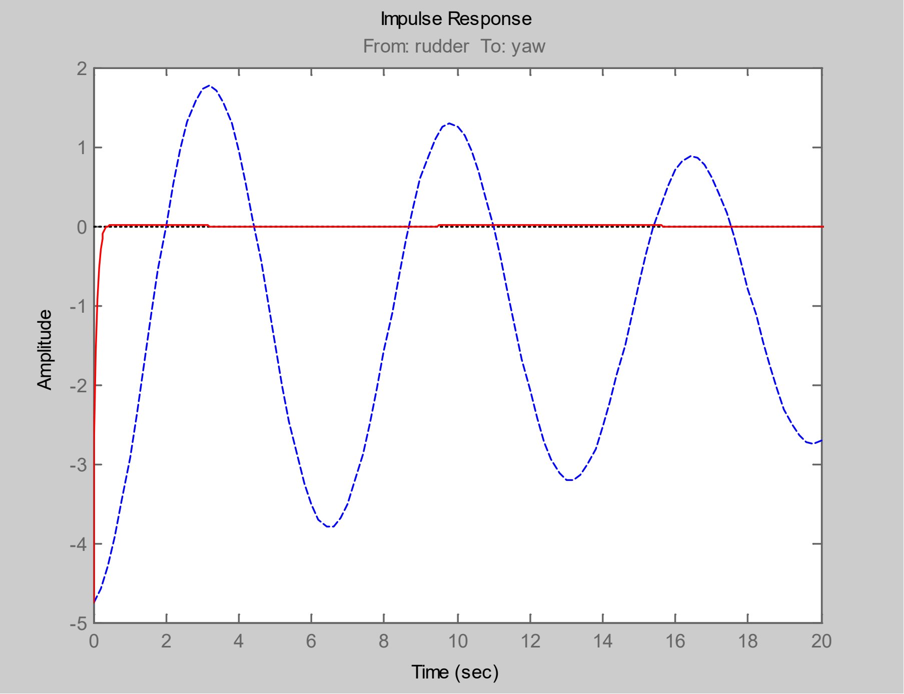

Fig. 5 Comparison of graphs of impulse responses for closed and open systems

The response of a closed-loop system with feedback is established quickly and does not fluctuate much, compared to the response of an open-loop system (Fig. 5).

As can be seen from Fig. 2 this MIMO system with r=2 inputs and m=2 outputs contains 2x2 mappings $u_i \to y_j$, $i = 1, \dots r$, $j = 1, \dots m$. Each mapping of the i-th input to the j-th output can be described by a scalar transfer function $Q_{ij}(p)$. Together they form a 2x2 matrix impulse function Q(p). In a MIMO system, feedback from output 1 to input 1 is considered, and for this case, using the *feedback* and *damp* commands, we obtain:

```
>> cloop = feedback (sys, -K,1,1);
>> damp(cloop)

        Eigenvalue                 Damping       Freq. (rad/s)

 -4.89e-001                      1.00e+000      4.89e-001
 -3.44e-002 + 5.05e-001i    6.80e-002      5.06e-001
 -3.44e-002 - 5.05e-001i     6.80e-002      5.06e-001
 -1.36e+001                     1.00e+000    1.36e+001
```

On Fig. 6 splitting the current graphic window for displaying comparative graphs of the impulse response of the MIMO system is performed using the function:

```
>> impulse (sys,'b--’, cloop,'r',20)
```

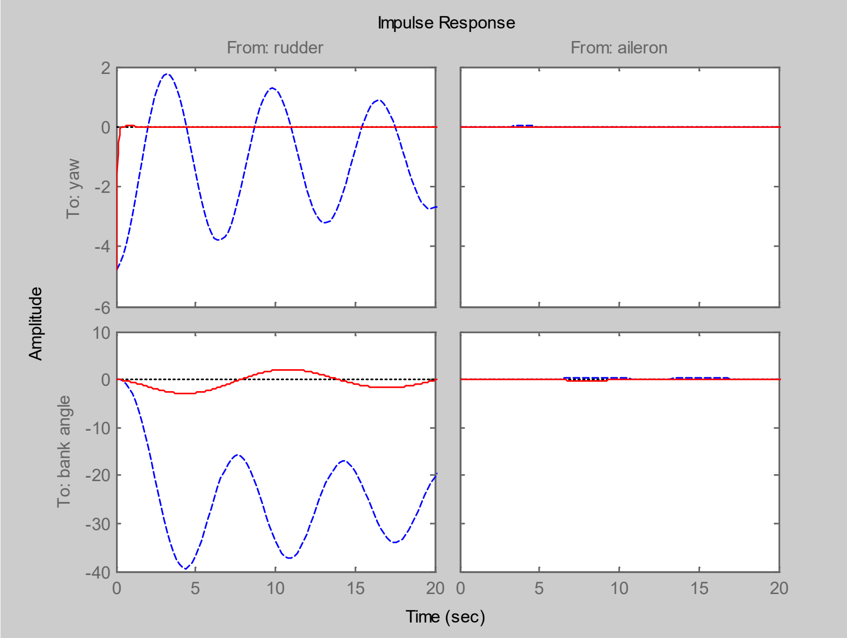

Fig. 6 Comparison of graphs of impulse response for closed and open systems

The yaw response now decays nicely, but look at the graph from ailerons (input 2) to bank angle (output 2). When you move the ailerons, the system no longer continues to bank like a normal UAV. You have over-stabilized the spiral mode. The spiral mode is typically very slow mode and allows the UAV to bank and turn without constant input of the ailerons.

Research results

It must be ensured that the spiral mode does not move further into the left half-plane when a closed system is considered. One way to solve this problem by developers of UAV control systems is to use a washout filter H (s), the transfer function of which has the form

$$H(s) = \frac{s}{s + a}$$

The washout filter places zero at the origin, causing the spiral mode pole to remain near the origin. For the time constant, a value is chosen such that a=0.2 and the root locus technique is used to find the filter gain k. First, using the *zpk* constructor, we write:

```
>> H = zpk (0, -0.2,1);
```

By connecting the washout filter in series with the sys11 design model (relationship between input 1 and output 1), the open-loop system can be written as follows:

```
>> oloop = H * sys11;
```

and for this open-loop system model, using the root locus method, we obtain (Fig. 7)

```
>> rlocus(-oloop)
>> sgrid
```

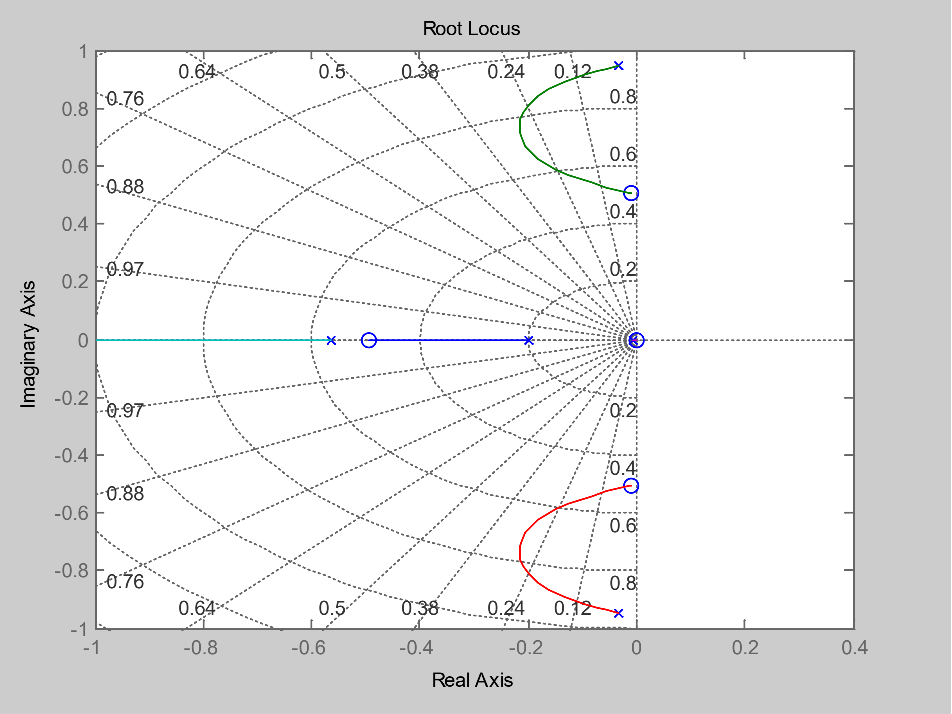

Fig. 7 Root locus of an open system when using a washout filter

By creating and dragging a data marker along the top curve in Fig. 7, the maximum damping can be determined, which is about $\zeta=0.3$.

From Fig. 7, it can be found that at the maximum damping coefficient, the gain is approximately 2.07.

Consider the impulse response for a closed system from input 1 (rudder deflection) to output 1 (torque for yaw)

```
>> K = 2.07;
>> cl11 = feedback (oloop, -K);
>> impulse(cl11,20)
```

The calculated graph is shown in Fig. 8.

The response is well stabilized, but has less damping than in the previous case without the flush filter. It can be seen that the use of a washout filter eliminates the spiral mode problem. To do this, it is first necessary to form a complete washout filter kH(s)

```
>> WOF = -K * H.
```

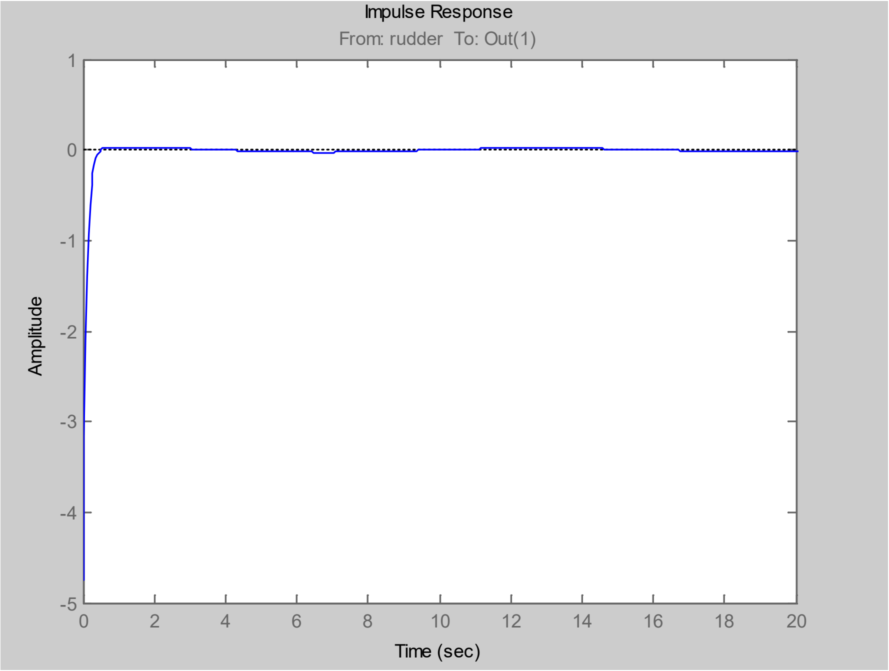

Fig. 8 Graph of the impulse response for a closed system from input 1 to output 1

When modeling MIMO systems sys with feedback from output 1 to input 1, control is given not in the form of a vector, but in the form of a matrix, and we find the system's response to the delta function:

```
>> cloop = feedback (sys, WOF,1,1);
>> impulse (sys,'b--’, cloop,'r',20)
```

The calculated curves are shown in Fig. 9.

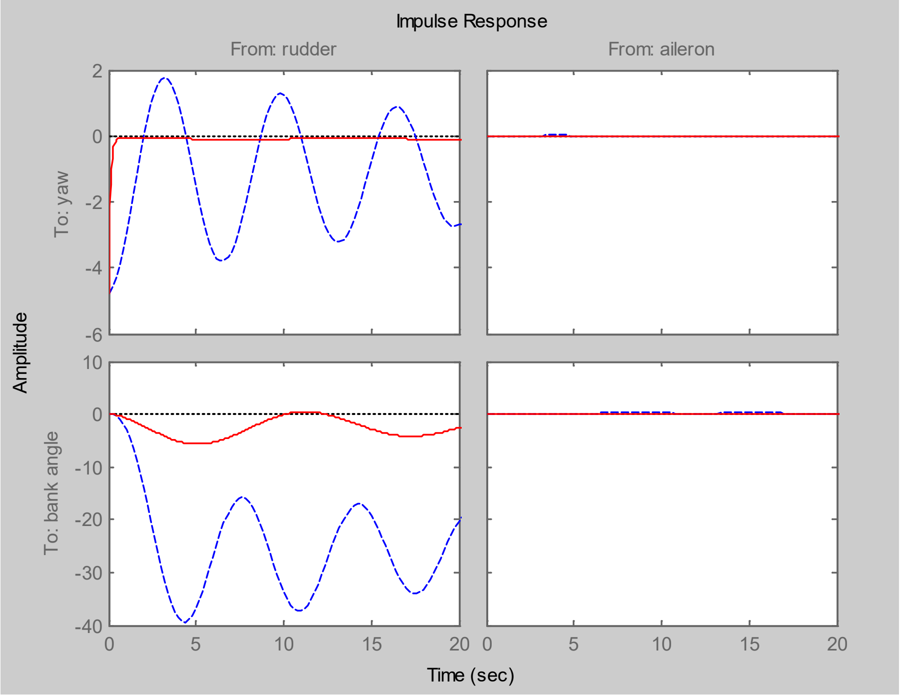

Fig. 9 Comparison of graphs of impulse response for open and closed systems when using a washout filter

The response of the MIMO system at output 2, i.e. the bank angle due to an input 2 aileron pulses is now at the desired, nearly constant value for this short period of time. For a more detailed study of the curve of dependence of the angle of bank on the aileron, the input-output selector in the menu called by the right mouse button (Fig. 10) is used.

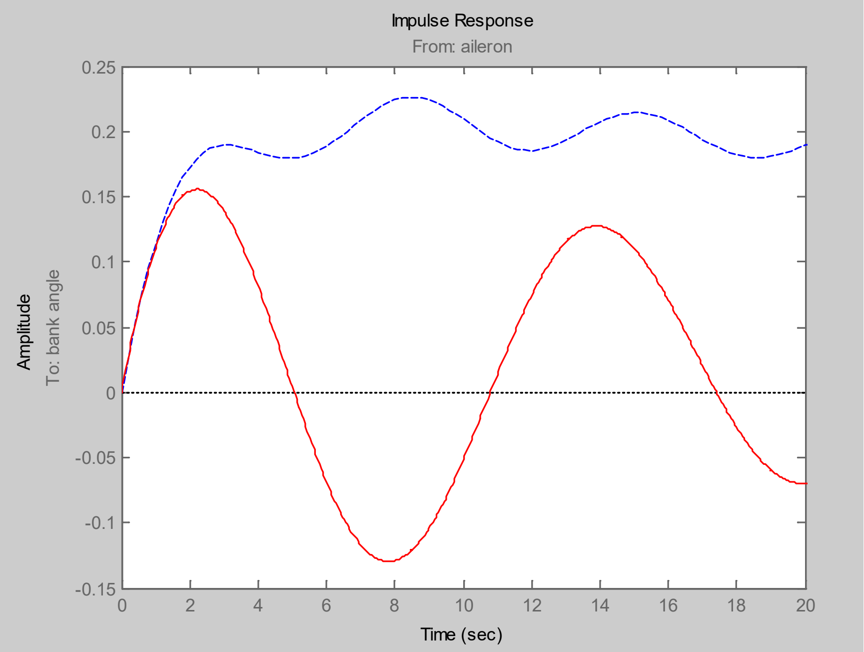

Fig. 10 Comparison of graphs of impulse response for open and closed systems in the case of an input-output pair = (2,2)

From Fig. 10 shows that for the developed design, the damping coefficient has increased significantly and now the controller controls the UAV in the normal mode.

Conclusion

The impulse response for the UAV yaw angle is shown in Fig. 5. Note that the yaw torque settling time is 0.1 s, which is much less than the settling time for an unregulated UAV (i.e., for an open loop system). We also note the complete absence of high-frequency oscillations in the impulse response for the yaw torque and the stationary error is zero. But for a simple controller, the UAV no longer continues to bank when the aileron deflection changes. Therefore, to eliminate the spiral mode, a washout filter is used as a regulator. In this case, the yaw torque response is well stabilized and the problem of spiral mode is eliminated at the same time. Thus, with the use of the washout filter, the impulse response of the UAV has improved significantly.

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MATLAB ՀԱՄԱԿԱՐԳԻ ՄԻՋՈՑՈՎ ԱՆՕԴԱՉՈՒ ԹՌՉՈՂ ԱՊԱՐԱՏԻ ԿԱՌԱՎԱՐՄԱՆ ՀԱՄԱԿԱՐԳԻ ՆԱԽԱԳԾՈՒՄ

Կիրակոսյան Գ.Հ., Մելքոնյան Վ.Ս., Ավետիսյան Ք.Ա.
Հայաստանի ազգային պոլիտեխնիկական համալսարան

Հիմնավորված է անօդաչու թռչող ապարատի աշխատանքային բնութագրերի վրա ուղղության ղեկի և էլերոնի շեղման ազդեցության հետազոտման և գնահատման անհրաժեշտությունը: Ցույց է տրված, որ կարգավորիչի բացակայության դեպքում տեղի է ունենում ընթացաշեղման անկյան պարբերական տատանումներ, որոնք երբեմն հասնում են մի քանի տասնյակ աստիճանի: Նոր մեթոդի վրա հիմնված լվացման ֆիլտր է մշակվել՝ բարելավելու ԱԹԱ-ի աշխատանքային բնութագրերը և թռիչքի ռեժիմները:

Բանալի բառեր. կառավարման համակարգ, անօդաչու թռչող ապարատ, գծային ստացիոնար դինամիկ համակարգ, ուղղության ղեկ, էլերոն, իմպուլսային կշռային ֆունկցիա, արմատային հոդոգրաֆ, լվացման ֆիլտր, հանդարտեցման գործակից:

ПРОЕКТИРОВАНИЕ СИСТЕМЫ УПРАВЛЕНИЯ БЕСПИЛОТНЫМ ЛЕТАТЕЛЬНЫМ АППАРАТОМ С ПОМОЩЬЮ СИСТЕМЫ MATLAB

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Обоснована необходимость исследования и оценки влияния отклонения руля направления и элерона на рабочие характеристики БПЛА. Показано, что при отсутствии регулятора имеют место периодические колебания угла рысканья, достигающие иногда нескольких десятков градусов. Разработан промывочный фильтр на основе нового метода для улучшения рабочих характеристик и режимов полета БПЛА.

Ключевые слова: система управления, беспилотный летательный аппарат, линейная стационарная динамическая система, руль направления, элерон, импульсная весовая функция, корневой годограф, промывочный фильтр, коэффициент демпфирования.

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