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UAV SPATIAL MOTION MODEL IDENTIFICATION

Abstract *UAV*[2] *includes wide variety of aircraft designed for special tasks. Many UAV applications use model aircraft to carry payload for several missions, i.e. UAV can be used for both non-military and military missions. Application of the common COTS*[3] *design philosophy generates many problems for designers having pure initial data of the aircraft. Flying in weak weather conditions, flying in pure visibility, and, finally flying beyond visual ranges requires automation of flight phases. Preliminary design of the autopilot systems requires of the dynamical model of the UAV. Purpose of the author is to give a methodology applied for identification of the UAV dynamical models used for automatic flight control systems' preliminary design purposes.*

I. INTRODUCTION

When the need of the UAV applications whether civilian or military arises several UAVs are available in the market to use. Many applications (i.e. border control, animal migration control, disaster monitoring, fire control etc.) generate need of the UAV flights by nights, or in poor visibility. This can be achieved by automation of the flight phases of the UAV flights. It is evident that any kind of automation and preliminary design of the automatic flight control systems of the UAV requires flight dynamics systems' models. A common question arises here: whether to buy, or to design a UAV for recce purposes? Present day there are lots of types of RC-models[4] of aircraft, which can fit preliminary requirements of test flights. The model aircraft market is full, and Cots-types can be chosen for research purposes. The article deals with problem statement of the identification of the UAV flight dynamics model, and with set-up of the identification process.

II. LITERATURE OVERVIEW

Author published series of paper dealing with conceptual design of UAVs both for military and non-military applications [1, 2, 3, 4, 5]. Dynamical system model identification is supported by MATLAB [6] and SIMULINK [8] progams supplemented with System Identification Toolbox [6]. For identification purposes there are given stochastic noise models applicable during identification [9]. Author dealt with identification problems of UAV dynamics in [10] and derived frame for the identification procedure.

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[2] **UAV** – **U**nmanned **A**erial **V**ehicle

[3] **Cots** – **C**ommercial-**o**ff-**t**he-**s**helves

[4] **RC** – **R**emotely **C**ontrolled

III. UAV MODEL IDENTIFICATION

The identification of the dynamical models has long history, and there are much powerful software supporting solution of this problem [6, 7, 8]. Being supported well in this field, author will give a short overview of the main principles and main steps of the identification process.

Dynamical system identification means estimating linear or nonlinear mathematical models to fit measured data from the dynamical system. The resulting dynamical model can be used for the analysis of the derived dynamical system, for the prediction of the system future responses, and finally, for the control design purposes. Identification based on system modeling cannot represent easily is called for *black-box* modeling. We can estimate linear mathematical models from data series given whether in time domain or in frequency domain.

Time domain data means one or more time domain inputs, $u_i(t)$, and one or more outputs, $y_i(t)$. Frequency domain data means the Fourier-transforms of the input and output time domain signals [6, 7, 8].

In general, the dynamical system identification might include following steps [6, 10]:

1. Experimental design and data acquisition.
2. Data analysis and preprocessing (plotting the data, removing offsets and linear trends, filtering, resampling, selecting new regions of the interest).
3. Estimation and validation of the dynamical models.
4. Model analysis and transformation (linear analysis, reducing model order, converting continuous models to discrete ones).
5. Model use for intended applications (simulation, prediction, preliminary control design).

It is well-known from control theory that system identification is an iterative process you identify dynamical models with different structures from the data and compare model performances. Finally, one chooses the simplest mathematical model that best describes the dynamics of the system being identified.

The system identification workflow can include following tasks and steps [6, 10]:

1. Prepare data for the system identification
   a. Importing data into MATLAB® workspace.
   b. Importing data into System Identification Tool GUI, or creating data objects in the MATLAB® Command Window.
   c. Plotting data to analyze them both in time and frequency domain. Deriving presence of the constant offsets, trends, delays, feedback, signal excitation level.
   d. Preprocessing data by removing offsets and linear trends, interpolating missing values, filtering to emphasize behavior in the specific frequency range.
2. Identify the linear, or the non-linear dynamical models
   a. Frequency response models.

b. Impulse response models.
c. Low-order transfer functions (process/plant models) – SISO models.
d. Input/output polynomial models.
e. State space models of the MIMO systems.
f. Non-linear *Black–Box* models.
g. *Grey–Box* models (ordinary differential, or difference equations).

The dynamical system model identification is explained on Figure 1.

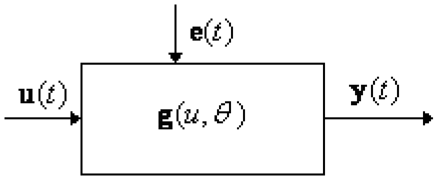

Figure 1. A scheme for model identification.

In Figure 1: $\mathbf{u}(t)$ - input vector; $\mathbf{y}(t)$ - output vector; $\mathbf{e}(t)$ - noise vector; $\mathbf{g}(u,\theta)$ - model of the dynamical system (linear or nonlinear one); θ - system parameter.

System Identification Toolbox provides following SISO linear models for further application [6]:

1. $Y(s)=\dfrac{K}{(1+sT_{p1})}$ – proportional (P) first order (O1) term;

2. $Y(s)=\dfrac{K}{s(1+sT_{p1})}$ – proportional (P) first order (O1), and integral term;

3. $Y(s)=\dfrac{K(1+sT_z)}{(1+sT_{p1})}$ – proportional (P) first order (O1) term with one zero;

4. $Y(s)=\dfrac{K(1+sT_z)}{s(1+sT_{p1})}$ – proportional (P) first order (O1) term with one zero and an integral;

5. $Y(s)=\dfrac{K(1+sT_z)e^{-sT_d}}{(1+sT_{p1})}$ – proportional (P) first order (O1) term with one zero and time delay;

6. $Y(s)=\dfrac{K(1+sT_z)e^{-sT_d}}{(1+2\xi T_w s+(T_w s)^2}$ – proportional (P) second order (O2) term having two poles with one zero and time delay;

7. $Y(s)=\dfrac{K(1+sT_z)e^{-sT_d}}{s(1+2\xi T_w s+(T_w s)^2}$ – proportional (P) second order (O2) term having two poles with one zero and time delay, and integral term;

8. $Y(s) = \dfrac{K(1+sT_z)e^{-sT_d}}{(1+2\xi T_w s + (T_w s)^2)(1+sT_{p3})}$ – proportional (P) second order (O2) term having three poles with one zero and time delay;

9. $Y(s) = \dfrac{K(1+sT_z)e^{-sT_d}}{s(1+2\xi T_w s + (T_w s)^2)(1+sT_{p3})}$ – proportional (P) second order (O2) term having three poles with one zero and time delay, and integral term.

The above listed models can be applied for models of the single input – single output (SISO) dynamical systems identification.

3. Validate models
   a. If one cannot achieve the appropriate and satisfactory model the different models can be used for identification purposes, or one must apply another identification algorithm. In some particular cases one can improve results by including a noise model, i.e. air turbulence models.
   b. Before system identification there might be a need of preprocessing data, i.e. a filtering can remove high-frequency noises, or maybe a resampling of the data can lead to a good result of the identification.
4. Simulate, or predict behavior of the dynamical system.
5. Additional step: design of the controller for the estimated plant using other MATLAB® toolboxes, or products (i.e. Control System Toolbox, Model Predictive Control Toolbox, Robust Control Toolbox, SIMULINK®).

IV. UAV FLIGHT PHASES AND REGIMES

If there is an ultimate decision about UAV type to be used for given purposes the question of automation of the flight phases arises, and must be answered. For further analysis and synthesis purposes the dynamical model of the aircraft is needed to be known. If the model aircraft is the COTS model aircraft its dynamical behavior and dynamical model is rarely derived.

Automation of the flight phases requires knowledge of the dynamical models of the spatial motion of the aircraft. The next question is: how to derive the aircraft spatial motion mathematical models?!

Firstly, let us derive preliminary the normal flight phases to be automatized [10]:

1. Take-off
2. Cruise
   a. Angular Control
   b. Direction Control
   c. Height Control
   d. Speed Control

e. Terrain following

3. Landing
    a. Descend
    b. Approach
        i. Glide path Control
        ii. Direction Control
    c. Flare
        i. Height Control
        ii. Speed Control

The flight phases given above are derived by the author definitely, and it is not the only unique set and is not the exclusive point of view. In other UAV applications there night be need of automation other flight phases discussed above.

For identification it is necessary to have main idea about identification process. If it is based on *data-driven modeling* one must have input signals, output signals, and noises of the process. The Cots–UAV can have, for instance, following input data of $u_i(t)$

1. angular deflection of the elevator;
2. angular deflection of the ailerons;
3. angular deflection of the rudders,
4. change in thrust;

and, can have following output data of $y_i(t)$

1. flight parameters of the longitudinal motion;
2. flight parameters of the lateral motion (if they can be separated from each other);

and, finally, can have disturbances, or noises of $e(t)$

1. external disturbance (i.e. atmospheric disturbance, other anomalies);
2. internal disturbances (i.e. sensor noises, other anomalies).

It is easy to see that COTS UAV can be described with mathematical models derived after identification of the dynamical systems' mathematical model. These models are necessary and sufficient ones for the on-board preliminary design of the automatic flight control system. As it was said before for this it is necessary to have time series of the input, and output signals, i.e. for the identification one must have on-board registered data of these signals. The registered data series can be stored onto on-board computer's memory, or can be broadcasted in real-time to the ground station unit for saving into special database. These time series must be converted into special MATLAB®

code available for importing into MATLAB® workspace for further analysis, and use for identification of the UAV spatial motion models.

V. SUMMARY AND CLOSING REMARKS

UAVs are useful tools to be applied for reconnaissance purposes in many civilian or military applications. They can be used very effectively in military missions having no pilots on the board. War theatre applications show that they are useful element of the very complex and modern digital battlefield. A new field of application is the war theatre D3 (Dull-Dirty-Dangerous) applications making possible keep human resources far behind the dangerous theatres.

Paper deals with basics of system identification procedure, namely, UAVs are involved into analysis. Steps for the identification process are detailed in the paper, and, further steps are nominated, i.e. for the given type pf the Cots–UAV a special flight plan must be created to have data series for identification of all possible discrete flight situations and conditions. A set of possible transfer functions of the model of the dynamical system is derived.

In the pre-conceptual and in the conceptual design phase of the automatic flight control system user must derive requirements for the Cots–UAV flights. This will drive steps both in identification and in controller synthesis tasks to be solved to have an UAV with autopilots.

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