Inverse Simulation Methods and Applications

ORGANISER AND TUTOR: Professor David J. Murray-Smith, Department of Electronics and Electrical Engineering, University of Glasgow.

GOAL: To increase awareness of methods and current applications of inverse simulation methods and to promote use of such techniques in the analysis and design of engineering systems, particularly in the context of aircraft and marine vehicles but also for other complex nonlinear systems applications.

ABSTRACT: Conventional approaches to simulation involve finding the response of a system to a particular input or disturbance. Inverse simulation reverses this and attempts to find the control inputs required to achieve a particular response. The technique has been applied in a number of fields but it is in aeronautical applications that it has found most favour so far, particularly in the context of rotorcraft flight. The piloting strategy required for an aircraft to perform a defined manoeuvre is predicted and can be used to analyse handling qualities, pilot workload, performance, manoeuvrability, agility and control system performance. Recently the methods have also been applied successfully to problems of ship manoeuvring and navigation and to underwater vehicles. The methods are particularly well suited to issues of actuator design and assessment of the effectiveness of control surfaces for applications of this kind. It is likely that these methods will prove useful in many other types of application in which actuator limiting can be important.

This tutorial introduces the general concepts of inverse simulation. Algorithms for inverse simulation will be presented from first principles and some selected applications will be discussed. The impact of inverse simulation methods in conveying real understanding about the dynamic properties of the system under investigation will be emphasised. Although aeronautical applications are dominant in the published work in this field, the methodology is far from being specific to flight control applications and any dynamic system may be treated in the same way. It is believed to be particularly appropriate for other complex nonlinear man-machine systems (or autonomous/semi-autonomous systems). Inverse simulation methods have also been found to be of value for the validation of complex dynamic models.

Specialist topics discussed in the tutorial include the large amplitude “constraint oscillations” that can sometimes be seen in responses predicted by the most widely used inverse simulation algorithms. Although such solutions are valid and may be seen in real flight data for tightly defined trajectories, inverse simulations showing such features are often treated with scepticism. Understanding of this phenomenon has recently improved and this important and fundamental topic will be discussed in some detail.

The use of inverse simulation techniques for the validation of complex nonlinear simulation models is discussed and some simple illustrations are provided. Potential benefits of inverse methods are discussed.

Links between inverse simulation and control algorithms that incorporate inverse models are also considered. Current research linking inverse simulation methods and predictive control techniques is outlined.

PROGRAMME:

1. "An introduction to inverse simulation methods and applications". (approx. 20 minutes).

This section involves an overview of the subject, giving an outline of the history of inverse simulation techniques to be discussed in the tutorial, an introduction to applications of inverse simulation and links between inverse simulation, model validation and control.

2. "Inverse simulation algorithms". (approx. 45 minutes).

This section includes a presentation of commonly used algorithms for inverse simulation and issues of numerical stability and accuracy. These include iterative methods based on differentiation and integration, use of feedback structures for generation of inverse models and methods based on DAE algorithms. The concept of "constraint oscillations" is introduced and discussed in the context of linear system dynamics before extending the concepts to the general nonlinear case.

3. "Application of inverse simulation methods to aircraft and ship manoeuvrability studies and inverse techniques in control". (approx. 40 minutes)

Results from the application of inverse simulation to studies of helicopter handling qualities, manoeuvrability and flight control are presented and discussed. Results obtained in ship manoeuvring studies are also presented. Problems arising in systems with dynamic properties that extend over a wide range of frequencies are discussed. Links between inverse simulation and inverse techniques in control are introduced.

15 minute break for refreshments.

3. Practical Work and/or Demonstrations (60 minutes)

Depending on the facilities available, practical hands-on experience of inverse simulation methods can be offered using established software environments such as MATLAB/SIMULINK. Alternatively demonstrations can be provided to illustrate the use of inverse simulation methods in a number of different applications.

TOTAL DURATION: 3 hours

POTENTIAL AUDIENCE: Engineers and researchers interested in modelling and simulation methods regardless of application area; control engineers and other man-machine system specialists; flight simulation and flight control specialists. Previous experience of inverse simulation techniques is not necessary. Previous experience with MATLAB and SIMULINK is useful for the practical work or for full understanding of the demonstrations.

RELEVANT EXPERIENCE OF TUTOR: Actively involved in two research projects involving inverse simulation methods and applications. Author of a number of journal papers and conference proceedings papers on this topic.