Active Stabilization of Unstable System Under Bounded Control with Application to Active Flutter Suppression Problem

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Certificate of Originality & Acknowledgements

This is to certify that I am responsible for the work submitted in this report, that the original work is my own except as specified in acknowledgements or in footnotes or in any other way. I also certify that this work has not been submitted previously to this or any other institution, for any other purpose.

____________________________________ (signed)

____________________________________ (date)

I would like thank my supervisor, Prof. M. Goman for his help and guidance. Many thanks also to all staff of the mechatronics lab for their help and technical assistance.

Abstract

Active stabilization of unstable systems is very important problem in engineering area. Many studies are directed to developing strategies for the suppression of different instabilities by active control for aircraft, bridges, monuments, etc. Some of these applications will be examined in the Thesis.

This project involved a novel approach to the problem of achieving almost global stability for simple Wing Section System, and improving stability of ECP inverted pendulum physical model by using a special technique – constructing α_{max} and h_{max} map for stability region evaluation.

The wing section has been built for experiments on the nonlinear aeroelastic test apparatus (NATA) in the 2.3 ft low-speed wind tunnel in Texas University. A unique feature of NATA is the presence of two cams that are fabricated to permit prescribed nonlinear responses in pitch and plunge.

The NATA testbed has been used successfully for investigations in the linear and nonlinear response of wing section in addition to the development of control design strategies.

For examination of dynamics of inverted pendulum, the ECP A-51 Inverted Pendulum, available in the School of Engineering at DMU, has been used. The ECP A-51 Inverted Pendulum is designed to enhance the utility of ECP systems by providing a modular add-on apparatus that utilizes the major functionality of the base unit. It can be configured to operate in inverted and noninverted modes and can be programmed to perform a self-inverting function.

Introduction

Motivation

Why some engineering systems are designed unstable? Usually they are designed as stable ones, however under certain operational conditions they can experience different kinds of instability, for example, aircraft wing flutter at high flight speeds. A designer can attain a high performance and agility for aircraft or a light low cost structure for bridges by implementing unstable configurations or expanding operational envelope by active stabilization of system dynamics. For example, fighter aircraft, may be intentionally designed unstable at some flight regimes to improve overall performance in the whole flight envelope. Aspiration to create, for example, a suspension bridge as longer and lighter as it is physically possible results in a need to stabilize it at the presence of high speed cross winds.

For this aim a lot of methods for passive stabilization have been developed, and recently more research is conducted for developing methods for active control stabilization. Stable systems normally have heavy and stiff structures and therefore are more expensive, while a stabilized unstable system is more light and flexible, but for expense that it can have limitations in magnitudes of external disturbances.

Active stabilization is a modern control strategy, which is based on implementation of automatic control technology to unstable objects to maintain their functionality providing them stability at specified operational conditions. Modern approach to design of some advanced engineering systems is based on unstable configurations, which are actively stabilized by control system. The impressive example of this design approach is the Segway transporter (Seg, n.d.).

Stable and unstable systems actively stabilized by control system have a potential to overcome many conventional design limitations. For example, an aircraft configuration usually

Figure 1: Eurofighter (intentionally unstable)

has critical unstable flight regimes associated with high incidence departure and it can face an aeroelastic instability at high speeds of flight. Another example is a very long suspension bridge under critical wind speed, which can have different kinds of flutter instability.

Normally, dynamics of engineering unstable system can be locally described by a linear time invariant system of ordinary differential equations with unstable eigenvalues. The unstable linear system with control constrains has a bounded control region. The size of control region for unstable engineering system can serve as a controllability measure for the design problems. If external disturbances move the system out of controllability region no controller is able to keep the system stable (Goman and Demenkov, 2004).

Aims and Objectives

The main aim of this project is to learn how to solve a task of active stabilization for nonlinear systems and to provide a key ideas and results, demonstrate theoretical, computational, and experimental capabilities and the degree to which correlation among results from these several approaches agree or disagree.

The active stabilization problem is currently extremely active area of research and there are many applications in this area. The advancement in this area will help to solve many engineering problems in the future.

The main objective of this research project is the investigation of different control strategies for active stabilization of unstable engineering systems with bounded control authorities, for example, aeroelastic aircraft structure, suspension bridges, self-balancing transportation systems, thermo-nuclear plasma generator (Tokamak), etc. Such actively stabilized systems in comparison with traditional stable ones can have many advantageous.

Outline of the Thesis

The whole project is divided into the following two parts:

1. **Theoretical and software development part**, which will include the comparative analysis of methods for control synthesis; development of computational tools, which will analyze stability region, implement different linear and nonlinear control laws, perform post design evaluation of different types of regulators for several models, i.e. an aeroelastic aircraft wing section and an inverted pendulum.
2. **Hardware part** will include evaluation of theoretical findings on a real physical model of inverted pendulum. For this purpose I will use special equipment, the inverted pendulum ECP A-51 model 210, available in the DMU School of Engineering.