Absolute Stability of Nonlinear Systems of Automatic Control

V. M. POPOV

A CENTRAL specification imposed on a control mechanism is invariably its stability. Maxwell's paper "On Governors" [10], settled the problem of stability of systems described by third order linear differential equations in terms of the coefficients of the associated characteristic polynomial. Subsequent to this paper, the problem of stability of systems described by linear differential equations in terms of the coefficients of the characteristic polynomial was solved by Routh and Hurwitz. It is worth noting that the mathematical problem of determining when the roots of a polynomial lie in the left half of the complex plane had actually been effectively solved by Hermite [5] a decade before Maxwell posed the stability problem as a question in control.

In his thesis in 1895, Lyapunov put forward a method, now called "the second method of Lyapunov", for determining the stability of an equilibrium of a system described by nonlinear differential equations. While Lyapunov was primarily interested in applications to mechanics, his method and stability concepts became very influential and widely applied in control. His ideas were especially popular in the Eastern European control literature, since it was customary in these countries to use differential equations as models for control mechanisms.

By contrast, in the Western literature, stability analysis in control had been centered on frequency-domain methods, propelled by the beauty, practicality, and generality (for linear systems) of the Nyquist criterion [11].

Each of these approaches has its advantages. Frequency-domain methods use very compact model specifications and are able to address robustness through gain and phase margins. However, the generalization to nonlinear systems of frequency-domain methods proved awkward. Differential equation models by and large proved a much better way of addressing nonlinearities.

Through the problem of determining conditions for the stability of systems with one nonlinear element, control witnessed a symbiosis between stability theory of Lyapunov methods and frequency-domain techniques. A key result that was the catalyst in this development that follows was Popov's stability criterion, the subject of the paper that follows.

The history of the problem is as follows (see [2] for more details). In 1944, Lur'e and Postnikov [7] formulated the problem of *stability in the large* of a finite dimensional system with one nonlinear element $f : \mathbb{R} \to \mathbb{R}$ satisfying $\sigma f(\sigma) \geq 0$ for all $\sigma \in \mathbb{R}$. In subsequent publications, Lur'e obtained, using Lyapunov methods, a set of "resolving equations" that allowed to conclude stability. These ideas were further developed in [9], [16], [8], but the resulting conditions remained difficult to verify and to interpret.

This problem of stability of a system with one nonlinear element led also to the *Aizerman conjecture* [1]. This states that if there exist k_1, k_2 such that $k_1 < \frac{f(\sigma)}{\sigma} < k_2$ for all $\sigma \in \mathbb{R}$, and if the linear system obtained by replacing the nonlinear element by a linear one with gain k, is asymptotically stable for all $k \in [k_1, k_2]$, then the nonlinear system is also asymptotically stable in the large. Aizerman's conjecture is valid for second order systems, but was proven to be false for third and higher order systems [12] (see also [14], [15]).

By introducing the frequency response of a system, Popov obtained a sufficient condition for the stability of such systems. This criterion can be formulated as follows. Consider the feedback system described by (see Figure 3 in Popov's article):

$$\frac{d}{dt}x = Ax + bu; \quad y = c^T x; \quad u = -f(y)$$

with $A \in \mathbb{R}^{n \times n}$, $b, c \in \mathbb{R}^n$, and $f : \mathbb{R} \to \mathbb{R}$ a continuous nonlinearity with $f(0) = 0$. Denote by G the transfer function of the linear part, i.e., $G(s) := c^T (Is - A)^{-1} b$. Assume furthermore that A is a stability matrix [meaning that $t \in \mathbb{R} \mapsto \exp(At) \in \mathbb{R}^{n \times n}$ is bounded on $[0, \infty)$]. The matrix A need not have all its eigenvalues in the open left half of the complex plane. In fact, Popov assumes that A has all its eigenvalues in the open left half of the complex plane, except, possibly, one eigenvalue at the origin. The assumption that A need not be Hurwitz in fact complicates his analysis considerably.

Popov proves that the equilibrium trajectory $x = 0$ is globally asymptotically stable if the following conditions are satisfied:

1. $\sigma f(\sigma) > 0$ for all $0 \neq \sigma \in \mathbb{R}$,

Absolute Stability Of Nonlinear Control Systems

Cheng-Fu Chen

Absolute Stability Of Nonlinear Control Systems:

   Absolute Stability of Nonlinear Control Systems Xiao-Xin Liao,2013-04-17 As is well known a control system always works under a variety of accidental or continued disturbances Therefore in designing and analysing the control system stability is the first thing to be considered Classic control theory was basically limited to a discussion of linear systems with constant coefficients The fundamental tools for such studies were the Routh Hurwitz algebraic criterion and the Nyquist geometric criterion However modern control theory mainly deals with nonlinear problems The stability analysis of nonlinear control systems based on Liapunov stability theory can be traced back to the Russian school of stability In 1944 the Russian mathematician Lurie a specialist in control theory discussed the stability of an autopilot The well known Lurie problem and the concept of absolute stability are presented which is of universal significance both in theory and practice Up until the end of the 1950 s the field of absolute stability was monopolized mainly by Russian scholars such as A 1 Lurie M A Aizeman A M Letov and others At the beginning of the 1960 s some famous American mathematicians such as J P LaSalle S Lefschetz and R E Kalman engaged themself in this field Meanwhile the Romanian scholar Popov presented a well known frequency criterion and consequently ma de a decisive breakthrough in the study of absolute stability   *Absolute Stability of Nonlinear Control Systems* Xiaoxin Liao,Pei Yu,2008-07-16 Following the recent developments in the field of absolute stability Prof Xiaoxin Liao in conjunction with Prof Pei Yu has created a second edition of his seminal work on the subject Liao begins with an introduction to the Lurie problem and Lurie control system before moving on to the simple algebraic sufficient conditions for the absolute stability of autonomous and non autonomous ODE systems as well as several special classes of Lurie type systems The focus of the book then shifts toward the new results and research that have appeared in the decade since the first edition was published This book is aimed to be used by undergraduates in the areas of applied mathematics nonlinear control systems and chaos control and synchronisation but may also be useful as a reference for researchers and engineers The book is self contained though a basic knowledge of calculus linear system and matrix theory and ordinary differential equations is a prerequisite   **Absolute Stability of Nonlinear Control Systems** Xiao-xin Liao,Xiaoxin Liao,1993   *A STUDY OF ABSOLUTE STABILITY IN NONLINEAR CONTROL SYSTEMS.* SUDHINDRANATH PYATI,1966   **On the Absolute Stability of Nonlinear Control Systems** Cheng-Fu Chen,1970   Absolute Stability of Nonlinear Control Systems I. H. Mufti,1966   **On Absolute Stability of Nonlinear Control Systems and Differential Equations with Persistent Perturbations** Hua Ting Chieh,1966   **Stability of Nonlinear Control Systems** Lefschetz,1965-01-01 Stability of Nonlinear Control Systems   *On Absolute Stability of Nonlinear Control Systems and Differential Equations with Persistant Perturbations* Hua Ting Chieh,1966   **Absolute Stability Studies of Nonlinear Control Systems** Octavio Maizza Neto,1973   **The Absolute Stability of a Nonlinear Control System** Forrest Therrill Valentine,1965   **Stability in Nonlinear Control Systems** Aleksandr Mikhailovich Letov,2015-12-08 The author a Nobel

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Nonlinear Control Systems Zoran Vukic,2003-02-04 This text emphasizes classical methods and presents essential analytical tools and strategies for the construction and development of improved design methods in nonlinear control It offers engineering procedures for the frequency domain as well as solved examples for clear understanding of control applications in the industrial electrical process manufacturing and automotive industries The authors discuss properties of nonlinear systems stability linearization methods operating modes and dynamic analysis methods phase trajectories in dynamic analysis of nonlinear systems and harmonic linearization in dynamic analysis of nonlinear control systems operating in stabilization mode   **Absolute Stability of Nonlinear Automatic Control Systems [with List of References]** ,1965

Investigation of Nonlinear Control Systems. Part 5. Piece-wise Linear Methods and Absolute Stability Nicholas Minorsky,MINORSKY (NICHOLAS) AIX-EN-PROVENCE (FRANCE),1964   **Nonlinear Control Systems Design 1989** A. Isidori,2014-05-23 In the last two decades the development of specific methodologies for the control of systems described by nonlinear mathematical models has attracted an ever increasing interest New breakthroughs have occurred which have aided the design of nonlinear control systems However there are still limitations which must be understood some of which were addressed at the IFAC Symposium in Capri The emphasis was on the methodological developments although a number of the papers were concerned with the presentation of applications of nonlinear design philosophies to actual control problems in chemical electrical and mechanical engineering   Theory of Nonlinear Control Systems Nicolai Minorsky,1969

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