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COMPUTER SCIENCE MEETS AUTOMATION

VOLUME I

Session 1 - Systems Engineering and Intelligent Systems
Session 2 - Advances in Control Theory and Control Engineering
Session 3 - Optimisation and Management of Complex Systems and Networked Systems
Session 4 - Intelligent Vehicles and Mobile Systems
Session 5 - Robotics and Motion Systems

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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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2 Advances in Control Theory and Control Engineering

52^{nd} Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
10 – 13 September 2007

O. Katernoga / V. Popov / A. Potapovich / G. Davydau

Methods for Stability Analysis of Nonlinear Control Systems with Time Delay for Application in Automatic Devices.

SECTION HEADING 2

We investigated stablilty of nonlinear feedback systems, in which it is possible to separate a linear continuous part (LCP) from a nonlinear part (NP). Let's consider a formation method of of mathematical models for discrete-time control systems (NDCS) on the following example. The characteristic $\varphi(\sigma)$ of random nonlinearity belongs to the sector $(0,k)$ and satisfies to the following conditions:

$$\varphi(0)=0;\, 0<\frac{\varphi(\sigma)}{\sigma}<k;\, \lim_{\sigma\to\infty}\varphi(\sigma)\neq 0, \qquad (1)$$

where k is the constant given value, $k=y/\sigma$. In the Tsypkin's work [1] it is shown, that a sufficient condition of absolute stability of the position equilibrium for all $\overline{\omega}$ frequencies in the range $[0,\pi]$ is performance of the inequality [1]. It is corresponding to discrete system with NP (1) and a stable linear discrete part of the open-loop system (LDP). This inequality after updating by means of the advanced Z-transform according to the technique [1], i.e. replacement of expressions $\exp(\mathrm{j}\overline{\omega})$ and the frequency transfer function $W^*(\mathrm{j}\overline{\omega},0)$ of the open-loop system, (where: $z=\exp(\mathrm{j}\overline{\omega})$, $\overline{\omega}=\omega T$, $\forall\,\overline{\omega}\in[0,\pi]$ and LDP with the transfer function $G^*(z,\varepsilon)$), we shall receive for values in the interval $-1<z<1$ and $\varepsilon=0$ in the next form

$$\operatorname{Re} G^*(z,\varepsilon)+k^{-1}>0. \qquad (2)$$

Let's carry out geometrical research of stability analysis of the NDCS with time delay in complex plane $z=\delta^*+\mathrm{j}\omega^*$, ($\mathrm{j}^2=-1$). In case of the stable LDP [1], the root locus of the effective frequency response $W^*(\mathrm{j}\overline{\omega},0)$, is located completely on the right of the vertical straight line, which is passing through a point located on valid axis of a complex plane of frequencies. We investigated the discrete-time systems with time delay

$$T_{\mathrm{d}}=nT+lT\,, \qquad (5)$$

where T_{d} is time delay in a direct circuit or the plant (prosess); *T* is the sampling period; nT and lT are accordingly the whole and fractional part of delay, $n=0,1,2,\ldots,$. When $0\le l\le 1$, we appled the Z-transform. In case of when value $T_{\mathrm{d}}<<T$, i.e. $l<<1$ we applied the advanced Z-transform.

Time delay (5) in a direct circuit we considered, included consistently with LCP, an element of pure delay with the transfer function which represent in the form of [4]

$$W_{\mathrm{d}}(p)=k_d\cdot\exp\left(-nT\,p\right)\exp\left(-lT\,p\right). \qquad (6)$$

For analysis of absolute stability NDCS with delay in case $T_{\mathrm{d}}<<T$ we used the transfer function LDP in following:

$$G^*(z)=D(z)\,W_{\mathrm{h}}W_{\mathrm{p}}(z)\,W_{\mathrm{d}}(z)\,, \qquad (7)$$

where $D(z)$ is the transfer function of discrete filter ; $W_{\mathrm{n}}W_{\mathrm{p}}(z)=Z\{W_{\mathrm{n}}(p)\,W_{\mathrm{p}}(p)\}$, where Z - is a symbol Z-transform, $z=\exp(T\,p)$; $W_{\mathrm{h}}(p)$ and $W_{\mathrm{p}}(p)$ are accordingly the transfer functions of the zero-order hold and LCP without taking into account delay; $W_{\mathrm{d}}(z)\approx z^{-(n+1)}[(1-l)\,z+l\,]$ is Z-transform (6), and $Z\{\exp(-lT\,p)\}=\exp\left[-l\,(z-1)\,z^{-1}\right]\approx\approx[(1-l)z+1]\cdot z^{-1}$, i.e. is approximated by a linear member of the Tayloris series. In case $T_{\mathrm{d}}<T$ of the transfer function LDP it is possible to present in the form

$$G^{*}(z,\varepsilon)=z^{-n}\cdot D(z)\cdot \mathrm{Z}_{\varepsilon}\{W_{\mathrm{n}}(p)\,W_{\mathrm{p}}(p)\}\big|_{\varepsilon=1-l}\ ,$$

where Z_{ε} is a symbol of the advanced Z-transform, $\varepsilon=1\text{-}l,\ 0<\varepsilon\le 1$ where $p=\mathrm{d}/\mathrm{d}t$. The transfer function LDP of system with the time delay T_{d} can be written in the form

$$G^{*}(z,\varepsilon)=G_{0}^{*}(z,\varepsilon)\cdot G_{\mathrm{d}}^{*}(z,\varepsilon), \tag{3}$$

where $$G_{0}^{*}(z,\varepsilon)=P_{0}^{*}(z,\varepsilon)/\,Q_{0}^{*}(z)=\sum_{j=0}^{m}b_{j}(\varepsilon)\,z^{m-j}\Big/\sum_{i=0}^{n}a_{i}\,z^{n-i} \tag{4}$$

is the transfer function LDP without taking into account time delay, $b_{j}(\varepsilon)$ and a_{i} are the real constant coefficients, $m\le n$;

$$G_{\mathrm{d}}^{*}(z,\varepsilon)=P_{\mathrm{d}}^{*}(z,\varepsilon)/\,Q_{\mathrm{d}}^{*}(z)=\sum_{j=0}^{m'}b'_{j}(\varepsilon)\,z^{m'-j}\Big/\sum_{i=0}^{n'}a'_{i}\,z^{n'-i} \tag{5}$$

is the transfer function of time delay element, where $b'_{j}(\varepsilon)$ and a'_{i} are the real constant coefficients, $m'\le n'$.

The transfer function LDP (3) can be presented in complex form [2] as

$$G^{*}(z,\varepsilon)=\frac{P^{*}+\mathrm{j}R^{*}}{E^{*}+\mathrm{j}F^{*}}\cdot\frac{A^{*}+\mathrm{j}B^{*}}{C^{*}+\mathrm{j}D^{*}}=U^{*}(\delta^{*},\omega^{*})+\mathrm{j}V^{*}(\delta^{*},\omega^{*}), \tag{6}$$

where polynomial functions from two independent variables δ^{*} and ω^{*}, $P^{*}$is $P^{*}(\delta^{*},\omega^{*})$, E^{*}, A^{*}, C^{*}- the even degrees, i.e. the real parts accordingly following polynomials $P_{0}(z,\varepsilon)$, $Q_{0}(z)$, $P_{\mathrm{d}}(z,\varepsilon)$ and $Q_{\mathrm{d}}(z)$, R^{*}, F^{*}, B^{*} and D^{*} - the odd degrees, i.e. the imaginary parts set forth above functions, which are identical on structure and, hence, are defined under the following formula for finding of polynomials of the even degrees, i.e. the real parts polynomials of degree $\tilde{n}$ from z ,

$$\tilde{E}_{\tilde{n}}^{*}(\delta^{*},\omega^{*})=\sum_{i=0}^{N}\sum_{j=0}^{\tilde{n}-2i}(-1)^{i}\,C_{\tilde{n}-j}^{2i}\,\tilde{a}_{j}\,\omega^{*2i}\,\delta^{*(\tilde{n}-2i-j)} \tag{7}$$

and for finding of polynomials of the odd degrees, i.e. is the imaginary parts of polynomials of the degree $\tilde{n}$ from z:

$$\tilde{F}_{\tilde{n}}^{*}(\delta^{*},\omega^{*})=\omega^{*}\sum_{i=0}^{N}\sum_{j=0}^{n-2i-1}(-1)^{i}C_{\tilde{n}-j}^{2i+1}\,\tilde{a}_{j}\,\omega^{*2i}\,\sigma^{*(\tilde{n}-2i-j-1)}\ , \tag{8}$$

where C_{υ}^{λ} - the binomial coefficients; $\tilde{n}$ - the degree of polynomials from z, which can be equal n or m, (n'or m'); $\tilde{a}_{j}$ - the real coefficients, i.e. a_{i} or $b_{j}(\varepsilon)$, (a'_{i} or $b'_{j}(\varepsilon)$);

$$N=\begin{cases}\tilde{n}/2\ -\text{for even values }\tilde{n};\\(\tilde{n}-1)/2-\text{for odd values }\tilde{n}.\end{cases}$$

We received after transformation (6) in view of (7) and (8)

$$U^{*}(\delta^{*},\omega^{*})=\frac{(E^{*}P^{*}+F^{*}R^{*})(A^{*}C^{*}+B^{*}D^{*})-(E^{*}R^{*}-F^{*}P^{*})(B^{*}C^{*}-A^{*}D^{*})}{(E^{*2}+F^{*2})(C^{*2}+D^{*2})}. \tag{9}$$

For geometric interpretation of absolute stability of NDCS for the Z-plane we equated the inequality (2)

$$U^*\left(\delta^*, \omega^*\right) + k^{-1} = 0\,. \tag{10}$$

Having substituted expressions (9) and (10), we received the mathematical model NDCS in view of nonlinearity (1) and time delay in the form of the analytical equation, which is the root-locus of vertical straight line (RGVSL) for research in the Z-plane of absolute stability of the position equilibrium:

$$k\left[\left(E^*P^* + F^*R^*\right)\left(A^*C^* + B^*D^*\right) - \left(E^*R^* - F^*P^*\right)\left(B^*C^* - A^*D^*\right)\right] + \left(E^{*2} + F^{*2}\right)\left(C^{*2} + D^{*2}\right) = 0\,. \tag{11}$$

Let's considered properties of RGVSL for the NDCS in view of time delay by means of the equation (11) in the following cases:

1) $n > m$ and $n' > m'$. Let values $E^* = 0$, $F^* = 0$, $C^* = 0$, and $D^* = 0$. Then the left part of the equation (11) is identically equal to zero and, hence, the poles of the transfer function LDP located on the trajectory of roots. At values $P^* = 0$, $R^* = 0$, $A^* = 0$, and $B^* = 0$ the left part (11) is not equal to zero and, hence, the zeros $G^*(z,\varepsilon)$ do not located on the trajectory of roots. However, at value $k = \infty$ the zeros located on the trajectory of roots. 2) Values $n = m$ и $n' = m'$. This case is similar to the first case. 3) $m = 0$ и $m' = 0$. The $G^*(z,\varepsilon)$ does not contain zero. At values $E^* = 0$, $F^* = 0$, $C^* = 0$, and $D^* = 0$ the poles of functions LDP $G^*(z,\varepsilon)$ located on trajectory of roots. 4) $n = 0$ and $m' = 0$. The $G^*(z,\varepsilon)$ does not contain the poles. Zero of function $G^*(z,\varepsilon)$ at $P^* = 0$, $A^* = 0$ do not located on trajectory of roots, and at $k = \infty$ zeros of $G^*(z,\varepsilon)$ located on the trajectory of roots.

The geometrical analysis testify, that the branches non-degenerate RGVSL pass through the poles of $G^*(z,\varepsilon)$, and the zeros do not located on trajectories of roots at any value k, except for $k = \infty$ [2].

We have generated on the basis of the general theory [3] the root's condition for geometrical interpretation of absolute stability NDCS: that the position equilibrium in NDCS in view of time delay, and the stable linear discrete part and nonlinearity $\varphi(\sigma)$, satisfying to conditions (1), it was absolute stability in the sector $(0,\, k)$, there is enough, that RGVSL (11) completely was inside in the circumference of radius 1.0 with the center in the beginning of coordinates of the z – plane [2].

The mathematic models for some classes of continuous-time and discrete-time nonlinear control systems present analytical equations for construction trajectories of the concrete root locus on the complex plane *P* or *Z*, correspondingly. In calculations with computer-oriented methods of polynomial with two independent variables were used well-developed mathematical apparatus with the grafs tracing on the PC display. We have developed the method for analysis and the geometrical root criteria-tests for the absolute stability of nonlinear discrete-time control systems with time-delay [2,3].

These methods were applicated for controlling systems with time delay and may be realized in automatic devices [4].

Vibroacoustic protection system intended for voice data protection against leakages via acoustic channels and vibration channels from rooms far beyond the protection zone.The systems can be described as an automatically controlled source of acousticnoise and vibration, to mask voice, mountable into constructional elements of buildings and other possible acoustic channels of voice data leakage (depending on the voice signal level in a room to be protected). The system generates masking signals, such as white noise, speech-like signals, and white noise + speech-like signals, by virtue of which the voice data leakage channels are shuttered. The speech-like signals are generated by a microprocessor randomly, and correspond with all the formal properties of voice (formant nature of signals, pitch frequency, equal to that of the voice pitch to be masked; pauses between words) and may be adapted to a certain person [7].

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