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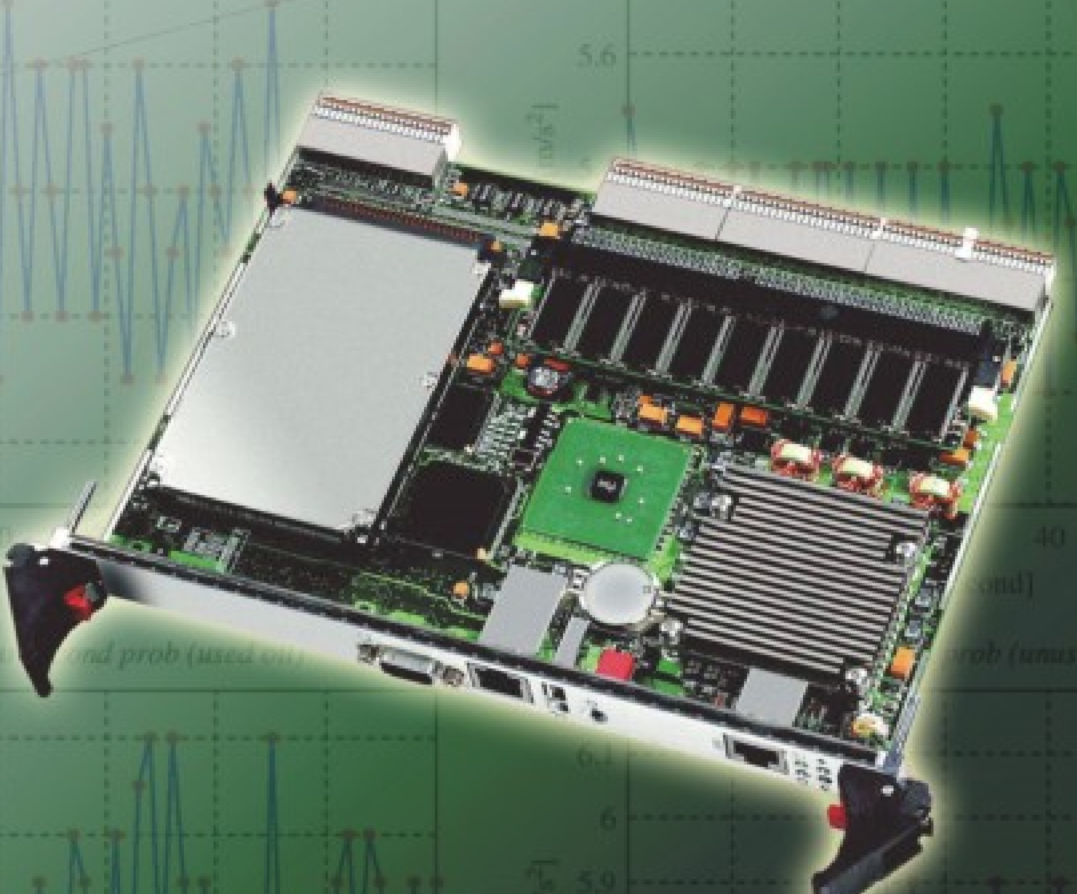

Intelligent Data Acquisition and Information Process Technologies and Their Applications. Part II

International Frequency Sensor Association Publishing

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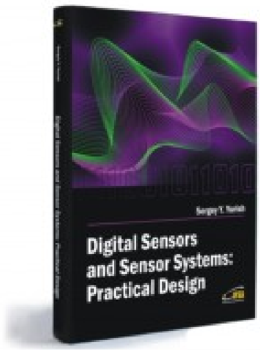
Digital Sensors and Sensor Systems: Practical Design

Sergey Y. Yurish



The goal of this book is to help the practicians achieve the best metrological and technical performances of digital sensors and sensor systems at low cost, and significantly to reduce time-to-market. It should be also useful for students, lectures and professors to provide a solid background of the novel concepts and design approach.

Book features include:

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Formats: printable pdf (Acrobat) and print (hardcover), 419 pages

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Digital Sensors and Sensor Systems: Practical Design will greatly benefit undergraduate and at PhD students, engineers, scientists and researchers in both industry and academia. It is especially suited as a reference guide for practicians, working for Original Equipment Manufacturers (OEM) electronics market (electronics/hardware), sensor industry, and using commercial-off-the-shelf components

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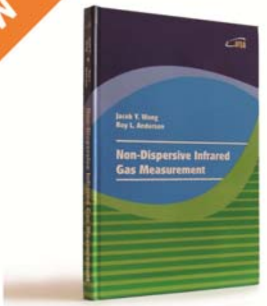
NEW BOOK

Jacob Y. Wong, Roy L. Anderson

Non-Dispersive Infrared Gas Measurement



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Providing sufficient background information and details, the book Non-Dispersive Infrared Gas Measurement is an excellent resource for advanced level undergraduate and graduate students as well as researchers, instrumentation engineers, applied physicists, chemists, material scientists in gas, chemical, biological, and medical sensors to have a comprehensive understanding of the development of non-dispersive infrared gas sensors and the trends for the future investigation.

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Application of Step Design Method to Realize the Synchronization of Genesio Chaotic System

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Abstract: In this paper, the synchronization of Genesio chaotic system is discussed. Based on the nonlinear cascaded system's stabilization theory and the time-limited stabilization theory, the controlled input step is designed. The simulation proves that step method is able to simplify Genesio chaotic system. The synchronization of Genesio chaotic system is realized. *Copyright © 2013 IFSA.*

Keywords: Chaos, Genesio system, Stepping design method, Synchronization

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1. Introduction

Stabilization design is fundamental problem of non-linear system. Because many problems, such as the design of detector, chasing, disturbance restrain, etc, will be concluded as non-linear system's stabilization problem after some transformation.

After 1970, academicians advanced kinds of methods to solve stabilization problems in common non-linear system [1-4]. The methods can solve different problems with their characteristics. In these methods, zero dynamic, controlling Lyapunov function, back-stepping method is effective. For example, Huang [5] use zero dynamic method realizes asymptotic chasing; Mrdjan Jankovic [6] use controlling Lyapunov function to solve robust stabilization problems; Zhang [7] and his coordinators use back-stepping design to control linear system of time-varying with known or unknown parameter. However, every method has its limit. Zero dynamic method demands that the zero dynamic sub-system is asymptotic stable. When use Lyapunov function, we must firstly find the controlling Lyapunov function in the system. When use back-stepping method, the system must be a special cascaded pattern.

This article puts forward a method of stepping disappearing. Firstly part of the system state is driven to origin, in the following design these states can substituted by 0. Because of the zero substitution, some items that are coupled with these states can be changed to 0. This kind of stepping design method can be applied to half decoupling non-linear system. In fact, many systems can be converted to half decoupling system, especially chaos system. In this article, this method is applied to realize the controlling and synchronization in chaos system. Stepping disappearing method is applied to realize the controlling and synchronization in the unified chaos system. The theory stepping disappearing method is researched, and it is applied to Genesio chaos system for its controlling and synchronization.

2. Basic Definition

Considering the following nonlinear system with p-dimesion input

$$\dot{x}_i = f_i\left(t, x, u_u\right) i = 1, 2, ..., p \, , \qquad (1)$$

where $x_i \in R^{n_i}, u_i \in R . x = \left[x_1^T, x_2^T, ..., x_p^T\right]^T$ and $u = \left[u_1, u_2, ..., u_p\right]^T$ is the state and input of the system. Nonlinear function $f_i\left(t, x, u_i\right)\left(i = 1, 2, ..., p\right)$ is plenty smooth. And suppose $f_i\left(t, 0, 0\right) = 0\left(i = 1, 2, ..., p\right)$, where origin is the balance point of the system [8].

Definition 1: If system $\dot{x}_i = f_i\left(t, x, u_i\right)(i = 1, 2, ..., p)$ is a feedback half decoupling system, system

$$\dot{x}_i = f_i\left(t, x, u_i(t, x, v_i)\right)\Big|_{(x_1=0, ... x_{i-1}=0)} = \bar{f}_i(t, x_i, v_i)(i = 1, 2, ..., p) \, , \qquad (2)$$

is a feedback half decoupling model of system (1).

Theorem 1: considering the following cascaded system.

$$\begin{aligned} \dot{x}_1 &= f_1\left(x_1\right), \\ \dot{x}_2 &= f_2\left(x_1, x_2\right), \\ \dot{x}_3 &= f_3\left(x_1, x_2, x_3\right), \\ &...... \\ \dot{x}_n &= f_n\left(x_1, x_2, ..., x_n\right). \end{aligned} \qquad (3)$$

in which $x_i \in R^{n_i} (i = 1, 2, ..., n)$. For any initial value, the solution of system (3) is bounded.

And if the following decoupling system's solution

$$\begin{aligned} \dot{x}_1 &= f_1\left(x_1\right), \\ \dot{x}_2 &= f_2\left(0, x_2\right), \\ \dot{x}_3 &= f_3\left(0, 0, x_3\right), \\ &...... \\ \dot{x}_n &= f_n\left(0, 0, ..., 0, x_n\right). \end{aligned} \qquad (4)$$

is globally asymptotic stable, system (4) is globally asymptotic stable.

Theorem 2: Suppose system (1) is feedback half decoupling, which means feedback control $u_i = u_i\left(t, x, v_i\right)\left(i = 1, 2, ..., p\right)$ can be found to get half decoupling system (2). If system (2) can be globally asymptotic stable by feedback $v_i\left(t, x_i\right) = \left(i = 1, 2, ..., p\right)$, and the solution of

$$\dot{x}_i = f_i\left(t, x, u_i(t, x, v_i\left(t, x_i\right))\right)\left(i = 1, 2, ..., p\right) \, , \qquad (5)$$

is bounded, system (3) is globally asymptotic stable [9].

Theorem 3: If we can design the following controller

$$\begin{aligned} \bar{u}_1 &= \varphi_1(t, x_1, x_2, ..., x_p), \\ \bar{u}_2 &= \varphi_2(t, x_2, ..., x_p), \\ &......, \\ \bar{u}_{p-1} &= \varphi_{p-1}(t, x_{p-1}, x_p), \\ \bar{u}_p &= \varphi_p(t, x_p), \end{aligned} \qquad (6)$$

which can stabilize the following system in limited time [10].

$$\dot{x}_i = f_i\left(t, 0, ..., 0, x_i, x_{i+1}, ..., x_p, \bar{u}_i\right)(i = 1, 2, ..., p)$$

Controller system (1)'s balance point $\left(x_1, x_2, ... x_p\right) = (0, 0, ..., 0)$ can be found by controller (6) within limited time.

3. Time Limited Chaotic Control for Genesio System

Genesio chaotic system is advanced by Genesio and his coordinators. It has many characteristics of chaotic system. It contains a simple quadratic term and 3 general linear differential equations, which depend on 3 positive real numbers. The dynamic system is described as following:

$$\begin{aligned} \dot{x}_1 &= x_2 \\ \dot{x}_2 &= x_3 \\ \dot{x}_3 &= -cx_1 - bx_2 - ax_3 + x_1^2, \end{aligned} \qquad (7)$$

where a, b, c is 3 positive real numbers, they satisfy ab<c. In this part, Genesio system is used to explain the stepping design method.

In this part, the origin time stable problem in Genesio system is considered. The controlled Genesio system is described as follows:

$$\begin{aligned} \dot{x}_1 &= x_2 + u_1 \\ \dot{x}_2 &= x_3 + u_2 \\ \dot{x}_3 &= -cx_1 - bx_2 - ax_3 + x_1^2 + u_3, \end{aligned} \qquad (8)$$

Step 1: Let $u_1 = -x_2 - x_1^{\beta} (0 < \beta < 1)$, the first equation of system (8) is changed to

$$\dot{x}_1 = x_2 + u_1 = -x_1^{\beta}, \tag{9}$$

Considering the optional Lyapunov function

$$V_1(x_1) = \frac{1}{2}x_1^2., \tag{10}$$

Along system (9) to get the solution

$$V_1(x_1) = -x_1^{\beta+1} = -2^{\frac{\beta+2}{2}} V_1^{\frac{\beta+1}{2}}., \tag{11}$$

Because 0 < β < 1, $0 < \frac{\beta+1}{2} < 1$. Controller $u_1 = -x_2 - x_1^{\beta}(0 < \beta < 1)$ can stabilize x1 in limited time, which means there is some time T1>0, after which $x_1 \equiv 0$.

Step 2: Let $u_2 = -x_3 - x_2^{\beta}(0 < \beta < 1)$, the 2nd equation of system (8) is changed to

$$\dot{x}_2 = x_3 + u_2 = -x_2^{\beta}, \tag{12}$$

Similar to the analysis did to x1, it can be proven that controller $u_2 = -x_3 - x_2^{\beta}(0 < \beta < 1)$ can stabilize x2 in limited time. There is some time T2>0, after which $x_2 \equiv 0$.

Step 3: Let $u_3 = -x_3^{\beta}(0 < \beta < 1)$. When $t > \max(T_1, T_2)$, $x_1 \equiv 0$, $x_2 \equiv 0$ is get. So when $t > \max(T_1, T_2)$,

$$\dot{x}_3 = -cx_1 - bx_2 - ax_3 + x_1^2 + u_3 = -ax_3 - x_3^{\beta}., \tag{13}$$

is get.
Considering the following Lyapunov function

$$V_2(x_3) = \frac{1}{2}x_3^2., \tag{14}$$

Along system (13) to differentiate (12) can get

$$\dot{V}_2(x_3) = x_3(-ax_3 - x_3^{\beta}) = -ax_3 - x_3^{\beta+1} \le -2^{\frac{\beta+1}{2}} V_2^{\frac{\beta+1}{2}}., \tag{15}$$

From theorem 2, controller $u_2 = -x_3^{\beta}(0 < \beta < 1)$ can stabilize Genesio chaotic system (8) within limited time.

4. Chaotic Synchronization in Genesio System

In this part, applying stepping design method is considered to realize chaotic synchronization. The drive system is as (7), the responding system is

$$\begin{aligned} \dot{y}_1 &= y_2 + v_1, \\ \dot{y}_2 &= y_3 + v_2, \\ \dot{y}_3 &= -cy_1 - by_2 - ay_3 + y_1^2, \end{aligned} \tag{16}$$

where v1 and v2 are the controller that will be designed to realize asymptotic synchronization. Record

$$e_1 = y_1 - x_1, e_2 = y_2 - x_2, e_3 = y_3 - x_3.$$

Equation (16) minus equation (7), the error system is as follows:

$$\begin{aligned} \dot{e}_1 &= e_2 + v_1, \\ \dot{e}_2 &= e_3 + v_2, \\ \dot{e}_3 &= -ce_1 - be_2 - ae_3 + e_1(x_1 + x_2)., \end{aligned} \tag{17}$$

Synchronization feedback controller is designed in 3 steps.

Step 1: Let $v_1 = -e_2 - k_1 e_1 (k_1 > 0)$, where appropriate k1 can be chosen to adjust convergence speed. The 1st equation of error system (17) is changed to

$$\dot{e}_1 = e_2 + v_1 = -k_1 e_1., \tag{18}$$

Obviously, system (18) is asymptotic stable. Hence, e1 can be asymptotic stabilized by linear feedback controller $v_1 = -e_2 - k_1 e_1 (k_1 > 0)$.

Step 2: Let $v_2 = -e_3 - k_2 e_2 (k_2 > 0)$. The 2nd equation of error system (17) is changed to

$$\dot{e}_2 = e_3 + v_2 = -k_2 e_2., \tag{19}$$

It's known after simple analysis. This system is asymptotically stable.

Step 3: Take the 3rd equation in system (17) into consider, which can be described as the following equation

$$\dot{e}_3 = -ce_1 - be_2 - ae_3 + e_1(x_1 + x_2). \quad (20)$$,

when e1=0, e2=0,

$$\dot{e}_3 = a e_3 . \quad (21)$$,

From the terms of theorem 1, the asymptotic stabilization of e3 needs system (17) to satisfy bounded terms. Under the effect of feedback control, the error system is

$$\begin{aligned} \dot{e}_1 &= e_2 + v_1 = -k_1 e_1, \\ \dot{e}_2 &= e_3 + v_2 = -k_2 e_2, \\ \dot{e}_3 &= -ce_1 - be_2 - ae_3 + e_1(x_1 + x_2). \end{aligned} \quad (22)$$,

From the up warding analysis we know $|e_1(t)| \le |e_1(0)|$, and $|e_2(t)| \le |e_2(0)|$. So e1 and e2 are both bounded. Considering the following Lyapunov function

$$V(e_3) = \frac{1}{2} e_3^2.$$

Along the 3rd equation of system (22) and differentiate it will get

$$\begin{aligned} V(e_3) &= e_3(-ce_1 - be_2 - ae_3 + e_1(x_1 + x_2)) \\ &= -ae_3^2 + e_3(-ce_1 - be_2 + e_1(x_1 + x_2)) \\ &\le -(a-\gamma)x_3^2 + \frac{1}{\gamma}(-ce_1 - be_2 + e_1(x_1 + x_2))^2 \\ &= -(a-\gamma)x_3^2 + \Pi \end{aligned} \quad (23)$$,

where $\Pi = \frac{1}{\gamma}(-ce_1 - be_2 + e_1(x_1 + x_2))^2$, γ is a positive constant with arbitrary chosen.

Because drive system (7) is a chaotic system, whose solution x1, x2 and x3 is bounded. From system (22) $|e_1(t)| \le |e_1(0)|$ and $|e_2(t)| \le |e_2(0)|$ is proven, therefore e1 and e2 is bounded, Π is bounded. From theorem 3 we get error (17) is asymptotic stable, which means in the effect of linear feedback control $v_1 = -e_2 - e_1$, $v_2 = -e_2 - e_3$, the response system (16) can asymptotically and synchronously drive Genesio chaotic system.

5. Simulation

4.1. This is a Subtitle Example

In the process of simulation, 4-step Runge-Kutta integral method is used to solve differential equation. To Genesio chaotic system (8), the parameter is set a = 1.2, b = 2.92, c = 6. Initial value is set to $(x_1(0), x_2(0), x_3(0)) = (5, -5, 1)$. The parameter in the controller is set β= 23. Fig. 1 shows the state responses of the controlled Genesion system (8), where the state track of Genesion system (8) converge to the origin.

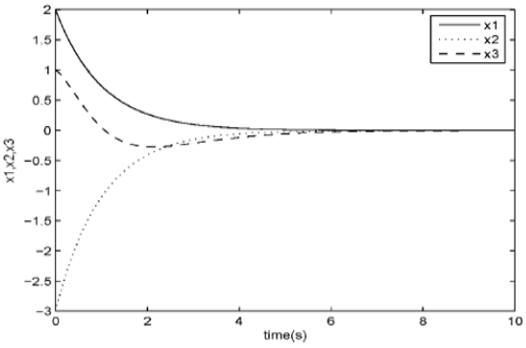

Fig. 1. The state responses of controlled Genesio chaotic system.

The initial state of drive system (8) is set to x1(0) = -1, x3(0) = -2, x1(0) = 1. The initial state of the response system (16) is set to y1(0) = 4, y2(0) = -4, y3(0) = 4. Fig. 2 to Fig. 4 is the effect of the chaotic synchronization in Genesio system. Fig. 5 is the effect of synchronic error response, in which system's state track asymptotically synchronous with drive system's state track.

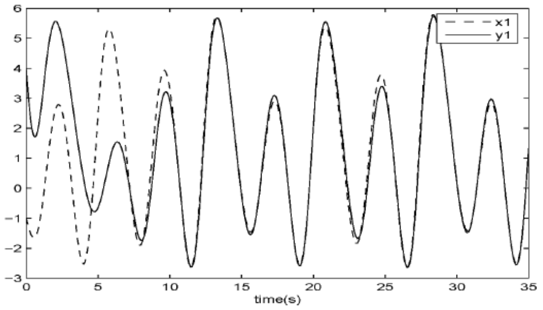

Fig. 2. Synchronization of Genesio chaotic system x1 and y1.

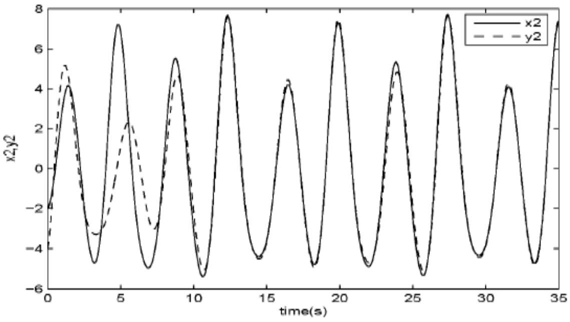

Fig. 3. Synchronization of Genesio chaotic system x2 and y2.

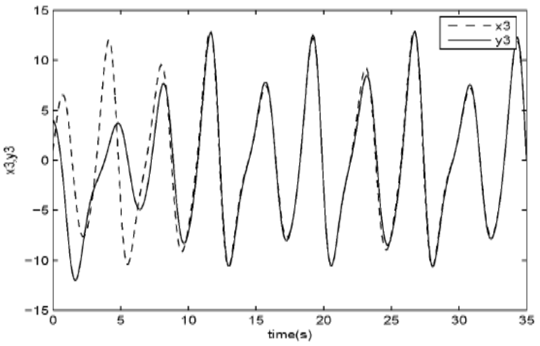

Fig. 4. Synchronization of Genesio chaotic system x3 and y3.

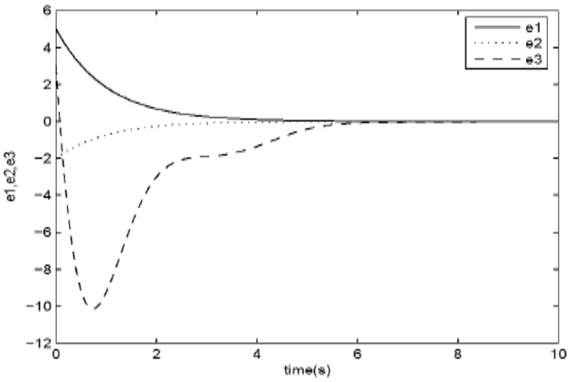

Fig. 5. Time response of the error system.

6. Conclusions

This article puts forward a new kind of stepping design method for one kind of half decoupling nonlinear system. And discuss how to apply this method to chaotic system. Based on nonlinear cascaded system's stabilization theory and limited time stabilization theory, the controlling input can be designed step by step. After each step, in the following cascaded sub-system more system states can be changed to 0 terms. Therefore, the nonlinear terms in the coupling can be changed to 0, and the system is simpler. The step design method has been applied to chaotic system's design. The simulation of Genesio chaotic system proves the effectiveness of this design method.

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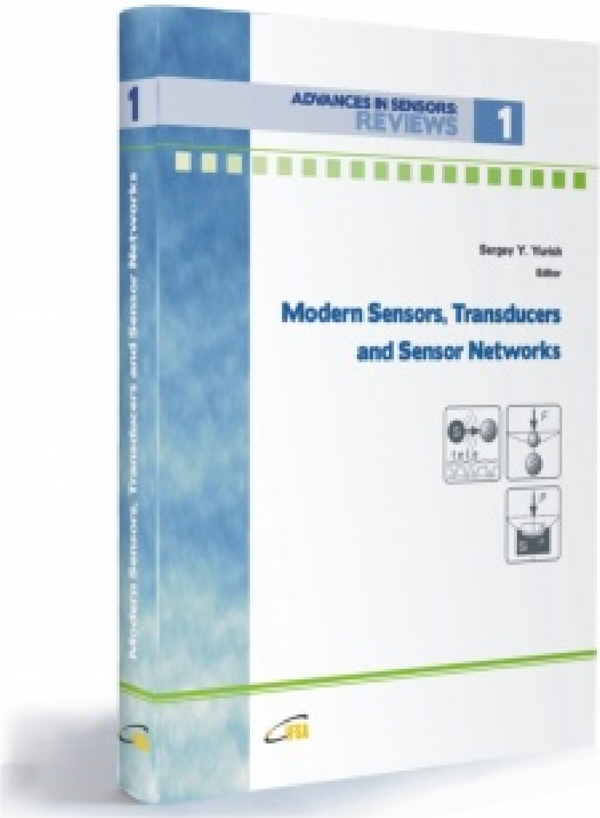
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