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Accuracy of Experimental Platform of Controlled Five-bar Linkages

Li Pan
College of Machinery and Automation, Wuhan University of Science and Technology,
Wuhan, 430081, China
Tel.: +86-027-68862283
E-mail: 1246989368@qq.com

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Abstract: Controlled mechanism is a new powerful subject. It is engendered with the developing of modern science and combined modern computer technique, control technique, sensor technique and other modern science and technology with old mechanisms. It is also engendered with the demand of high accuracy and high flexibility for modern machine. Controlled five-bar is an important area of contemporary mechanism. On account of the current gap in experimental platform and it's accuracy about five-bar, a controlled five-bar experimental platform (CFEP) has been designed and its accuracy was studied. Mathematical expression of the accuracy of experimental platform of controlled plate five-bar linkages was achieved by differential method. The accuracy quantitative of CFEP was analyzed using C++ programming. It is the theoretical design foundation of controlled five-bar linkages. *Copyright © 2012 IFSA.*

Keywords: Accuracy, Differential method, Five-bar linkages, C++, controlled five-bar experimental platform (CFEP).

1. Introduction

Multi-degree controlled mechanism is an important branch of contemporary mechanism. As the simplest multi-degree mechanism, controlled five-bar mechanism is becoming the hot spot of mechanism. Controlled five-bar mechanism has two initiative parts with one part motioning constantly and the other controlled by computer to give compensating motion, so the required track will be generated by one or more links on the mechanism. Professor Kong of Wuhan University of Science and Technology [1], professor Zhang Ce of Tianjin University [2] and professor Zou Huijun of Shanghai Jiaotong University

[3], etc. have made a lot of representative researches. Their researches are focused on realizing the track "accurately" for the starting point, and then are extended continuously. But documents [4, 5] break away from accurately realizing track and only study characteristic of five-bar mechanism, organization of itself only, put forward existence condition of double crank, type and singularity etc. The research results of these documents are undeniable, but the following subject matter exists: 1) Realize track of a few points position (about ten or twenty points), and can't reflect the inherent characteristic of realizing; 2) Initial purpose of five-bar mechanism is ignored, and it's very difficult to exist single crank of "accurately "realizing continuous track of five-bar mechanism; 3) There is a lack of design methods model universe and number value universe optimization "accurately" realizing the continuous track" of five-bar mechanism.

To make the experimental platform of controlled plate five-bar linkages work well, the geometrical parameters of five-bar linkages must be rationally ascertained. And the paper introduces how to determine the geometrical parameters of platform of controlled plate five-bar linkages [6]. Design of experimental platform of controlled plate five-bar linkages was introduced, but the accuracy of experimental platform is not discussed [7]. It is well known that the positioning precision and resolution of manipulators, including micro/nano manipulation systems, mainly depend on their topology and mechanical structures, actuators and transducers, sensing and measurement techniques, and control methodologies [8-11] and. Due to the backlash and stiction of the revolute joints and the geometric and dimensional errors of the components of the conventional manipulation systems, the conventional mechanisms cannot fulfill the requirements of the micro/nano manipulation tasks. Therefore, different mechanisms must be developed to overcome these problems. One of the best approaches to overcome the above problems is to utilize flexure-based mechanisms, where the conventional kinematic pairs are replaced by the flexure hinges. These types of joints have a number of advantages including no backlash, zero friction, and negligible hysteresis [12, 13]. In addition, such flexure-based mechanisms can be monolithically manufactured and thus reducing assembly errors and guaranteeing the machining accuracy [14].

The differential method is used to achieve the mathematical expression of the accuracy of experimental platform of controlled plate five-bar linkages, and C ++ programming is used to analyze the accuracy in quantity. The result provides a theoretical foundation of the design and application of controlled five-bar linkages.

2. Differential Method

Mechanism error is calculated by the follower movement principle. Obviously, position error of mechanism follower is shown as equation (1). Where Y is defined as actual position of mechanism follower, Y_0 is defined as ideal position of mechanism follower, X_i is defined as independent position parameters of ideal driving part and middle fittings, ΔX_i is defined as infinitely small number of total differential.

$F(X_i)-F_0(X_i)$ in equation (1) represents the method error in mechanism. If the design of actual institution is accurate, and there isn't the approximate design principle, then the method error is zero, namely, $F(X_i)=F_0(X_i)$ and position error ΔP of mechanism follower is expressed as equation (2).

Position error of mechanism follower is equal to the sum of local position errors caused by each original error, which is called independent action principle or superposition principle. Partial derivative in equation (2) is the scaling of each mechanism original errors transferred to the follower， which is called error transfer coefficient or error transfer ratio, and called error influence coefficient generally. Error influence coefficient varies, influence on follower position error ranges too. Mechanism accuracy, namely the relationship between mechanism position error and each original error, can be expressed by total differential of mechanism transmission equation actually. Infinitely small number of total differential ΔX_i can be replaced by $\Delta_i X_i$, for size parameter error of each mechanism is much smaller than its size. Hence, each partial derivative value of total differential is calculated and multiplied by responsive original error, and then error action principle is used to add each local error, the sum of follower position error is obtained. This is the differential method of calculation mechanism accuracy.

Some relevant factors are ignored in equation (2), for example there isn't design error and the effect of higher-order derivative is ignored. An approximation solution is got by differential method, but its accuracy is enough. So this method is often used to calculate mechanism accuracy.

$$\Delta P = \Delta Y = Y - Y_0 = F(X_i) - F_0(X_i) + \sum_{i=1}^{n}(\frac{\partial Y}{\partial X_i})_1 \Delta X_i, \quad (1)$$

$$\Delta P = \sum_{i=1}^{n}(\frac{\partial Y}{\partial X_i})_1 \Delta X_i = (\frac{\partial Y}{\partial X_1})_1 \Delta X_1 + (\frac{\partial Y}{\partial X_2})_1 \Delta X_2 + \cdots + (\frac{\partial Y}{\partial X_n})_1 \Delta X_n \quad (2)$$

3. Accuracy Calculation of Controlled Plate Five-bar Linkages

Track point P in Fig. 1 can be expressed as following.

$$\rho = \rho_0 + l_1 e^{i\phi} + re^{i(\phi_2+\alpha)} \quad (3)$$

$$x = x_0 + l_1 \cos\varphi + r\cos(\phi_2 + \alpha) \quad (4)$$

$$y = y_0 + l_1 \sin\varphi + r\sin(\phi_2 + \alpha), \quad (5)$$

where x_0, y_0 are coordinates of hinge point A; l_1 is the crank length; φ is the crank angle; r is the track rod length; α is the angle between track rod and connecting rod; φ_2 is the angle between rocker and X axis; φ_3 is the angle between support rod and X axis; l_2 is the connecting rod length; $l_3^{'}$ is the rocker length, namely the sum of initial four-bar rocker length and slide compensation distance; l_4 is the frame length.

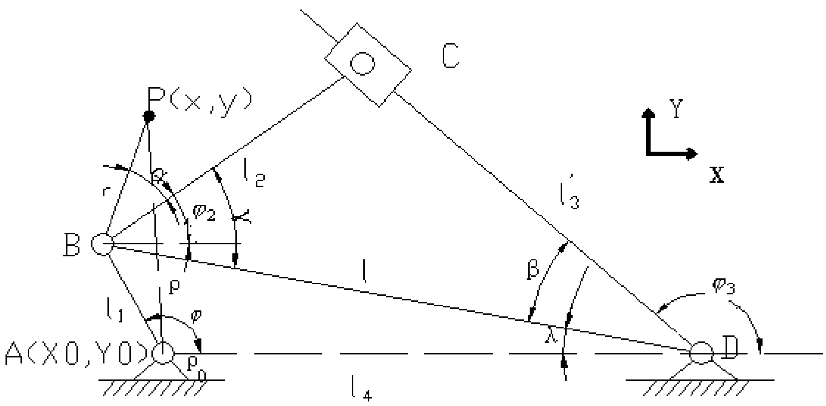

Fig. 1. Five-bar linkages track figure.

According to equation (2), derivation of x_0, l_1, l_2, $l_3^{'}$, l_4, φ, r, α by x are did respectively, error influence coefficient of above several parameters influence on track accuracy are got. Derivation should be paid attention as following. φ_2 is the implicit function of l_1, l_2, $l_3^{'}$, l_4, φ.Because compensation movement is sure, controlled five-bar linkages can be seen as four bar linkages. There are five independent variables in four bar linkages, namely Z=4+1=5.

$$\begin{aligned}\Delta x = \Delta x_0 + [\cos\phi - r\sin(\phi_2+\alpha)\frac{\cos(\phi-\phi_3)}{l_2\cos(\phi_2-\phi_3)}]\Delta l_1 - r\sin(\phi_2+\alpha)\frac{\cos(\phi_2-\phi_3)}{l_2\sin(\phi_2-\phi_3)}\Delta l_2 + r\sin(\phi_2+\alpha)\frac{1}{l_2\sin(\phi_2-\phi_3)}\Delta l_3^{'} \\ + r\sin(\phi_2+\alpha)\frac{\cos\phi_3}{l_2\sin(\phi_2-\phi_3)}\Delta l_4 + [-l_1\sin\phi + r\sin(\phi_2+\alpha)\frac{\frac{\partial[S(\phi)]}{\partial\phi}+l_1\sin(\phi-\phi_3)}{l_2\sin(\phi_2-\phi_3)}]\Delta\phi + \cos(\phi_2+\alpha)\Delta r - r\sin(\phi_2+\alpha)\Delta\alpha\end{aligned} \tag{6}$$

$$\begin{aligned}\Delta y = \Delta y_0 + [\sin\phi + r\cos(\phi_2+\alpha)\frac{\cos(\phi-\phi_3)}{l_2\cos(\phi_2-\phi_3)}]\Delta l_1 + r\cos(\phi_2+\alpha)\frac{\cos(\phi_2-\phi_3)}{l_2\sin(\phi_2-\phi_3)}\Delta l_2 - r\cos(\phi_2+\alpha)\frac{1}{l_2\sin(\phi_2-\phi_3)}\Delta l_3^{'} \\ - r\cos(\phi_2+\alpha)\frac{\cos\phi_3}{l_2\sin(\phi_2-\phi_3)}\Delta l_4 + [l_1\cos\phi - r\cos(\phi_2+\alpha)\frac{\frac{\partial[(S\phi)]}{\partial\phi}+l_1\sin(\phi-\phi_3)}{l_2\sin(\phi_2-\phi_3)}]\Delta\phi + \sin(\phi_2+\alpha)\Delta r + r\cos(\phi_2+\alpha)\Delta\alpha\end{aligned} \tag{7}$$

And $\rho^2 = x^2 + y^2$ derivate ρ by l_1, l_2, $l_3^{'}$, l_4, φ, r, α, there is:

$$|\frac{\partial\rho}{\partial l_1}| = |\frac{x[\cos\phi - \frac{r\sin(\phi_2+\alpha)\sin(\phi-\phi_3)}{l_2\cos(\phi_2-\phi_3)}] + y[\sin\phi + \frac{r\cos(\phi_2+\alpha)\sin(\phi-\phi_3)}{l_2\sin(\phi_2-\phi_3)}]}{\sqrt{x^2+y^2}}| \tag{8}$$

$$\frac{\partial\rho}{\partial l_2}| = |\frac{x[-r\sin(\phi_2+\alpha)\frac{\cos(\phi_2-\phi_3)}{l_2\sin(\phi_2-\phi_3)}] + yr\cos(\phi_2+\alpha)\frac{\cos(\phi_2-\phi_3)}{l_2\sin(\phi_2-\phi_3)}}{\sqrt{x^2+y^2}}| \tag{9}$$

$$\frac{\partial\rho}{\partial l_3^{'}}| = |\frac{x\frac{r\sin(\phi_2+\alpha)}{l_2\sin(\phi_2-\phi_3)} + y\frac{r\cos(\phi_2+\alpha)}{l_2\sin(\phi_2-c)}}{\sqrt{x^2+y^2}}| \tag{10}$$

$$\frac{\partial\rho}{\partial l_4}| = |\frac{x\frac{r\sin(\phi_2+\alpha)\cos\phi_3}{l_2\sin(\phi_2-\phi_3)} + y\frac{-r\cos(\phi_2+\alpha)\cos\phi_3}{l_2\sin(\phi_2-\phi_3)}}{\sqrt{x^2+y^2}}| \tag{11}$$

$$|\frac{\partial\rho}{\partial\phi}| = |\frac{x[-l_1\sin\phi + \frac{r\sin(\phi_2+\alpha)[\frac{\partial[S(\phi)]}{\partial\phi}+l_1\sin(\phi-\phi_3)]}{l_2\sin(\phi_2-\phi_3)}] + y\{l_1\cos\phi - \frac{r\cos(\phi_2+\alpha)[\frac{\partial S(\phi)}{\partial\phi}+l_1\sin(\phi-\phi_3)]}{l_2\sin(\phi_2-\phi_3)}\}}{\sqrt{x^2+y^2}}| \tag{12}$$

There is the following geometric relationship in Fig. 1.

$$l = \sqrt{l_1^2 + l_4^2 - 2l_1l_4\cos\phi} \tag{13}$$

$$\lambda = \arccos\frac{l_4^2 + l^2 - l_1^2}{2l_4 l} \tag{14}$$

$$\beta = \arccos\frac{l_3'^2 + l^2 - l_2^2}{2l_3'l} \tag{15}$$

$$\gamma = \arccos\frac{l_2^2 + l^2 - l_3'^2}{2l_2l} \tag{16}$$

$$\varphi_2 = \gamma - \lambda \tag{17}$$

$$\varphi_3 = \pi - \lambda - \beta \tag{18}$$

From the above equations, error influence coefficients of each parameter are all functions along with the change of φ, and φ is the crank angle changing between the cycles of $0-2\pi$, so error influence coefficient is the cycle function of φ. Length size of controlled plate five-bar linkages is put into equation (6) ~ equation (18), error influence coefficients of l_1, l_2, l_3', l_4, φ, r, α can be got. In order to simplify the problem, assuming that there is no installation error of linear motor, that is to say, the parallel degree error between linear motor and slider is zero in Fig. 1. And the Installation position deviation of linear motor is zero, so the length of l_3' consists of connecting rod length l_3 and slider compensation distance $S(\varphi)$. In experimental platform of controlled plate five-bar linkages, slider compensation distance $S(\varphi)$ is achieved by controlling linear motor motivation, the motion accuracy of which is 0.001 mm. Hence, its motivation error can be ignored, and the error of l_3' is only the error of connecting rod length l_3.

4. Accuracy of Experimental Platform

There are following parameters in the experimental platform of controlled plate five-bar linkages. $l_1 = 100mm$, $l_2 = 390mm$, $l_3' = 655mm + S(\phi)mm$, $l_4 = 576mm$, $\alpha = 15^\circ$, $S(\phi) = 5\sin\varphi$, using $C++$ to program, error influence coefficient curve of such l_1, l_2, l_3', l_4, φ, r, α by x, y, ρ and maximum error influence coefficient of each parameter can be got (note: X, Y and ρ in the figure respectively represents partial derivative the above parameter by x, y, ρ, namely error influence coefficient).

5. Results Analysis

From Figs. 2-8, maximum error influence coefficient of each parameter occurs in different phase. Hence, it is impossible that each original error maximum (namely maximum tolerance) occurs at the same time, and it's much impossible that errors add in the same direction. In addition, length error has a little effect on track accuracy in the instance, but the angle error has large effect on track accuracy. Error influence coefficients of l_2, l_3, l_4 and r are all smaller than 1. In other words, they reduce length error, which has a little effect on track accuracy. But l_1 is opposite rightly, it has a bigger effect on track accuracy. And error influence coefficient of both two angles φ and α is bigger, for example, when $\Delta\varphi$ =1°, $\Delta\rho_{\max} = 4.096 \times 1 = 4.096$ mm. From the above analysis, angle has a bigger effect on track accuracy, so manufacturing accuracy in actual manufacture must be controlled strictly.

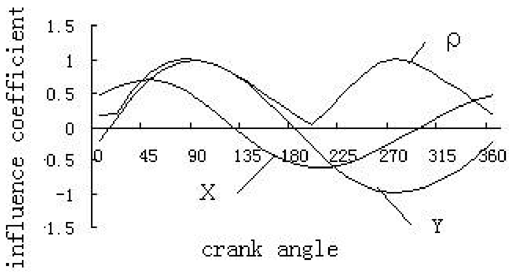

Fig. 2. Error influence coefficient of l_1 .

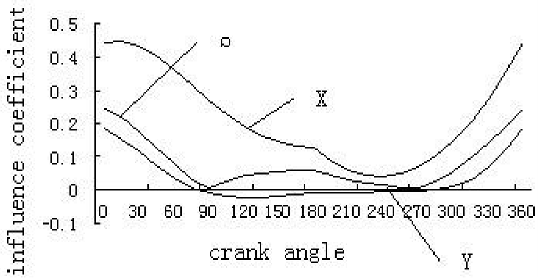

Fig. 3. Error influence coefficient of l_2 .

6. Conclusion

Controlled five-bar has become the hot spot of contemporary mechanism as the simplest multi-degree mechanism. So far, some theory outcomes of controlled five-bar have been achieved. However, as the practical achievement of theory, accuracy of experimental platform about five-bar linkages is seldom encountered. Ordinary expression of controlled plate five-bar linkages realizing tract is concluded by differential approach. The error effect factors of each parameter are calculated by C++ programs and analysis and synthesis of accuracy are studied by statistics means. It provided a reliable and practical work platform for researching and applying controlled mechanism.

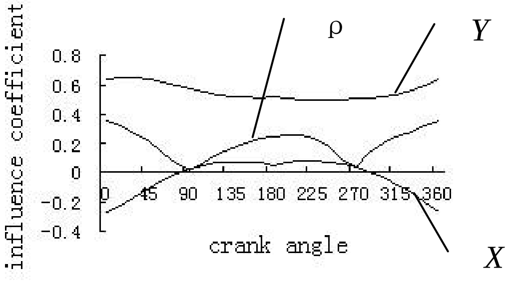

Fig. 4. Error influence coefficient of l_3' .

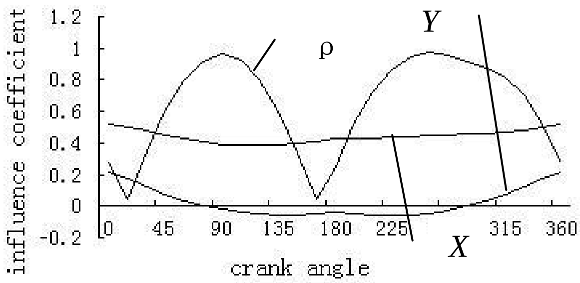

Fig. 5. Error influence coefficient of l_4.

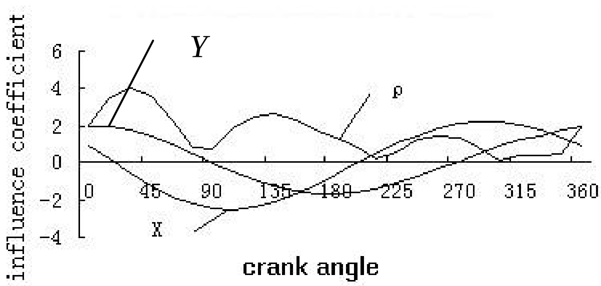

Fig. 6. Error influence coefficient of rank angle φ

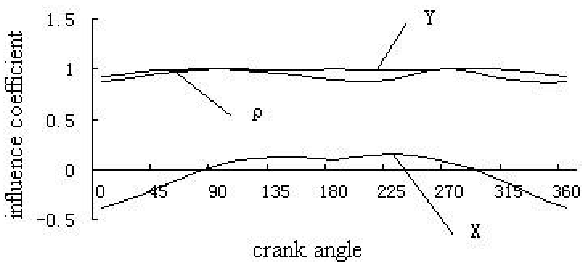

Fig. 7. Error influence coefficient of track stem *r*.

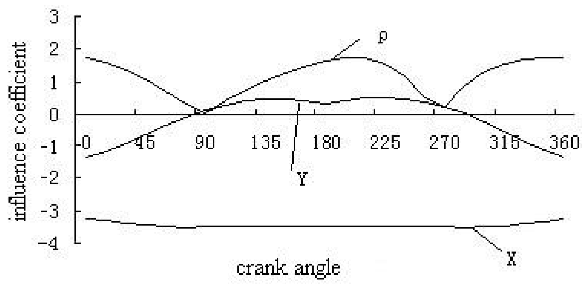

Fig. 8. Error influence coefficient of angle α between track stem and connecting rod.

References

[1]. Jianyi Kong, Ein Beitrag Zur Mabsyntyese Ebener Funfgliedriger Koppelgetriebe, PhD. Thesis, Dept. Mechanical Engineering, *University of Federal Defense Force Hamburg*, Hamburg, German, 1994.

[2]. Xinhua Zhang, Ce Zhang, Hanming Tian, Inverse-kinematics Synthesis Problems of 2-DOF Linkages Achieving the Group-tracks Accurately, *Chinese Journal of Machine Design*, Vol. 10, Issue 10, 2001, pp. 9-12.

[3]. Hong Zhou, Huijun Zou, Optimal Synthesis of Adjustable Crank-rocker Linkages for Continuous Path

Generation, *Chinese Journal of Mechanical Engineering*, Vol. 36, Issue, 11, 2000, pp. 19-22.
[4]. Balli Shrinivas S, Chand Satish, Five-bar motion and path generators with variable topology for motion between extreme positions, *Mechanism and Machine Theory*, Vol. 37, Issue 11, 2002, pp. 1435-1445.
[5]. H. Zhou and Kwun-Lon Ting, Path generation with singularity avoidance for five-bar slider-crank parallel manipulators, *Mechanism and Machine Theory*, Vol. 40, Issue 3, 2005, pp. 371-384.
[6]. Li Pan, Jianyi Kong, Jintang Yang, Determination of the geometrical parameters of platform of controlled plate five-bar linkages, *Journal of Wuhan University of Science and Technology*, Vol. 27, Issue 2, 2004, pp. 148-149.
[7]. Li Pan, Jianyi Kong, Jintang Yang, Experimental platform design of controlled plate five-bar linkages, *Mechanical Transmission*, Vol. 1, Issue 3, 2004, pp. 54-56.
[8]. G. Alici, B. Shirinzadeh, Enhanced stiffness modeling identification and characterization for robot manipulators, *IEEE Transactions on Robotics*, Vol. 21, Issue 4, 2005, pp. 554–564.
[9]. G. Alici, B. Shirinzadeh, A systematic technique to estimate positioning errors for robot accuracy improvement using laser interferometry based sensing, *Mechanism and Machine Theory*, Vol. 40, Issue 8, 2005, pp. 879–906.
[10]. P. L. Teoh, B Shirinzadeh, C. W. Foong, G. Alici, The measurement uncertainties in the laser interferometry-based sensing and tracking technique, *Measurement*, Vol. 32, Issue 2, 2002, pp. 135–150.
[11]. Y. Tian, B. Shirinzadeh, D. Zhang, G. Alici, Development and dynamic modelling of a flexure-based Scott–Russell mechanism for nano-manipulation, *Mechanical Systems and Signal Processing*, Vol. 23, Issue 3, 2009, pp. 957–978.
[12]. D. Zhang, D. G. Chetwynd, X. Liu, Y. Tian, Investigation of a 3-DOF micro-positioning table for surface grinding, *International Journal of Mechanical Sciences*, Vol. 48, Issue 12, 2006, pp. 1401–1408.
[13]. N. Lobontiu, J. S. N. Paine, Design of circular cross-section corner-filleted flexure hinges for three-dimensional compliant, Journal of Mechanical Design, *Transactions of ASME*, Vol. 124, Issue 3, 2002, pp. 479–484.
[14]. S. T. Smith, V. G. Badami, J. S. Dale, Y. Xu, Elliptical flexure hinges, *Review of Scientific Instruments*, Vol. 68, Issue 3, 1997, pp. 1474–1483.

Guide for Contributors

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Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because of it is a peer reviewed international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per year by International Frequency Sensor Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc. Since 2011 the journal is covered and indexed (including a Scopus, Embase, Engineering Village and Reaxys) in Elsevier products.

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- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
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- Technologies and materials;
- Nanosensors;
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