

Retraction

Retracted: Application of Virtual Reality Technology in Teaching and Training System of Processing Industrial Robot

Wireless Communications and Mobile Computing

Received 25 July 2023; Accepted 25 July 2023; Published 26 July 2023

Copyright © 2023 Wireless Communications and Mobile Computing. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

- (1) Discrepancies in scope
- (2) Discrepancies in the description of the research reported
- (3) Discrepancies between the availability of data and the research described
- (4) Inappropriate citations
- (5) Incoherent, meaningless and/or irrelevant content included in the article
- (6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

 Q. Chen, "Application of Virtual Reality Technology in Teaching and Training System of Processing Industrial Robot," *Wireless Communications and Mobile Computing*, vol. 2022, Article ID 3415660, 8 pages, 2022.



Research Article

Application of Virtual Reality Technology in Teaching and Training System of Processing Industrial Robot

Qinglai Chen 🕩

Mechatronics System, Huaibei Vocational & Technical College, Huaibei, Anhui 235005, China

Correspondence should be addressed to Qinglai Chen; 20153100040@m.scnu.edu.cn

Received 26 July 2022; Revised 27 August 2022; Accepted 8 September 2022; Published 20 September 2022

Academic Editor: Balakrishnan Nagaraj

Copyright © 2022 Qinglai Chen. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

In order to solve the problem of difficult teaching and slow teaching in the traditional teaching method of industrial robots, a virtual reality technology is proposed in the teaching and training system of industrial robots. The binocular vision module is fixedly connected to the end tool of the robot to reduce the limitation of teaching range. A hand-held teaching device with a feature plate and a position and pose measuring rod is designed to teach the position and pose of set points quickly. The least square method is used to calibrate the translation parameters of the end of the feature plate. The system collects the image of the feature plate of the hand-held teaching device through binocular vision module and processes the image to obtain the position and pose information of the end points; the pose information is converted to the robot base coordinate system to realize the robot teaching reproduction, and then the teaching position is 2.427 mm; after using mobile demonstration, the mean position error decreases by 25.3%. *Conclusion*. The application of virtual reality technology in the teaching and training system of virtual reality technology in the teaching and training system of machining industrial robot can improve the accuracy of teaching repretition.

1. Introduction

Industrial robot technology with computer science and control theory of mechanical and electrical engineering and information technology such as the development of technology has gradually become a standard equipment that is widely used in welding assembly handling a variety of domains such as glue. Industrial robots in raising the level of industrial production automation at the same time greatly reduce the labor costs and improve production efficiency. In addition, as the country attaches great importance to manufacturing and the transformation and upgrading of traditional industries, while promoting the construction of new infrastructure, the demand for high-quality industrial robot application talents is more urgent. Currently, more and more opened industrial robot technology specialty in higher vocational colleges, in the course of industrial robot teaching, need to rely on specific industrial robot workstation, related equipment price is higher, the space is larger, the restriction of the funds and site conditions, school training equipment quantity is less, the classroom 5-6 students share

a set of equipment, and embrace operation time is very limited. Aimed at the limitations of operating time, training equipment, and students in the teaching process, through the virtual simulation software to simulation and debugging of workstation, then to test the physical equipment, it can reduce the training costs and improve the training efficiency and teaching effect, and it will also to a certain extent solve the students' self-study before class and after class development stage without machine problems with entity operations.

Sensing technology with computer technology and network communication technology, especially in the context of industrial 4.0, intelligent manufacturing (IM) has been further developed. Intelligent manufacturing has become the main direction of a new round of industrial technology reform in China's manufacturing industry. It integrates the development of artificial intelligence, flexible manufacturing, virtual manufacturing system, control network, integrated information processing, and other disciplines and technologies. Specially, virtual reality technology in mechanical engineering (e.g., parts and components maintenance in machine tool design) in the field of application greatly promoted the machinery intelligent manufacturing implementation of major projects. Virtual reality (VR) is a computer system that creates people and the world. It is a humancomputer interaction tool. Simulation using virtual reality technology makes people feel like they are in the scene and can manipulate and interact with extremely complex data. According to the different degrees of user participation and sense of immersion, virtual reality system is usually divided into desktop virtual reality system, immersive virtual reality system, and distributed virtual reality system.

This VR technology is also known as virtual integrated display technology in social practical applications. It is an extension of multimedia technology and the crystallization of intelligent research on computer technology and intelligent sensing technology. The technology allows the human body to touch the virtual world and provide a relatively realistic vision of the virtual space. Research on VR technology has been extended to various fields, including medical industry, disease diagnosis, industrial production, policy predicsimulation tion, and hydrogeological exploration. Workshop training is a key point to VR technology application, in terms of design and the relevant operational system, the theory of mechanical production and standardized production process as the basis, by calling the high and new technology, to participate in training personnel to provide a relatively true, and can meet the demand of real-time interaction of information and resources of all automation workshop [1], as shown in Figure 1.

2. Literature Review

With the continuous development of robot technology, industrial robots have occupied a pivotal position in the field of industrial production in human society. Ordinary industrial robots need to be taught before moving. At present, the traditional way is teaching reproduction and offline programming. In teaching reproduction mode, the position and posture of the robot end-effector need to be adjusted repeatedly. The whole teaching process is time-consuming and labor-consuming, which reduces the working efficiency of the robot. In addition, the operator should be close to the robot to observe the robot when the robot moves, resulting in personal safety risks. Offline programming has higher security, but it needs to build models separately according to different workpieces. In the face of changeable workpieces and processing requirements, heavy preliminary work reduces production efficiency.

In view of the shortcomings of the above traditional teaching methods, many scholars combined binocular vision technology with robot teaching to improve teaching efficiency. Ortt, R. proposed a stereo vision teaching method based on binocular camera, which controlled the robot's repeated motion based on fuzzy set theory until the robot reached the specified teaching point [2]. In the teaching process, Wang, Z. collected binocular vision images of objects, extracted object edges through digital image processing method, calculated three-dimensional coordinates of object center, and generated teaching path through spatial fitting

difference method of dimensional transformation [3]. The above methods mainly analyze and calculate the processing path through image processing and data optimization, so as to improve the teaching efficiency. However, the lack of robot end tool pose data source has certain limitations in practical application. Therefore, in this paper, binocular vision system is used to continuously take the image of the teaching handle with calibration object and record the motion trajectory of the handle [4]. This method converts the pose information of the teaching handle in the camera coordinate system to the robot base coordinate system to realize the complex trajectory reproduction. However, this method is not universal and requires the robot end-effector and the teaching handle to have the same shape. A teaching programming system for industrial robot based on visual guidance is proposed, which uses a teaching tool with calibration to carry out continuous teaching and converts it into robot motion instruction, so as to realize the reproduction of teaching trajectory [5]. Maslivetc, V. A., builds a visual system to observe teaching tools. Once the system is calibrated, neither the robot nor the visual system can move, which limits the teaching space and movement range of the robot to a certain extent [6].

Aiming at the limitations of binocular vision technology in robot teaching, a robot fast teaching system is proposed by installing binocular vision module on the end tool of the robot to form an eye-on-hand model [7]. The coordinate system transformation of the fast teaching system is studied, and the least square method is used to calibrate the handheld teaching device designed. Finally, the fast teaching reappearance experiment and mobile teaching experiment are carried out with the system.

3. Method

3.1. Binocular Vision Teaching System

3.1.1. Principle of Binocular Vision Ranging. Binocular vision structure is based on the principle of human eyes observing the outside world, the image information of the same target under two cameras is processed and calculated, and the depth information of the target in binocular stereo vision system is calculated by triangular parallax method, so as to obtain the position, shape, and posture information of the target in three-dimensional space [8].

In the parallel binocular vision system structure, the two cameras placed in parallel, two camera coordinate system exists only between two optical center around a translational transform camera attachment b is called the baseline, zero PL and PR d is called the parallax, the coordinates of the difference between using parallax d and similar triangle principle, calculation point P in parallel binocular stereo vision system of three-dimensional coordinate information [9].

The established coordinate system $o_L - x_L y_L z_L$ and $o_R - x_R y_R z_R$ is the coordinate system of the two cameras with the center of light as the origin. The two cameras are placed in parallel, and the optical axes of the two cameras are parallel, that is, $o_L - x_L y_L z_L$ and $o_R - x_R y_R z_R$; the coordinate system is parallel [10]. Plane A and B are the imaging planes of



FIGURE 1: Virtual reality technology.

TABLE 1: Visual system parameter.

Model of camera	MV-CE050-30GM		
Distinguishability	2592x1944		
Focal length	4 mm		
Baseline distance	80 mm		
Working distance	600 mm		
Field of view	900mmx700mm		

the left and right cameras, respectively, and the projection points of points P(X, Y, Z) on the imaging planes of the left and right cameras are, respectively $P_L(X_L, Y_L, Z_L)$ and $P_R(X_R, Y_R, Z_R)$. In order to obtain parallax *d*, the imaging plane of the right camera is shifted to the imaging plane of the left camera, so that the two imaging planes are overlapped, and the projection point on the imaging plane P_R ' of the left camera P_R is obtained as shown in Formula (1):

$$d = X_L - X_R,\tag{1}$$

$$Z_L = Z_R = f. \tag{2}$$

In Formula (2), it is the focal length of the camera.

In order to obtain the three-dimensional coordinate information of point P in the binocular vision coordinate system, let K be the translation displacement of the imaging plane of the right camera, that is, the distance between the optical axes of the two cameras (baseline length b) [11]. fand K were obtained by binocular camera parameter calibration. According to the similar triangle theorem, the relation between parallax D and depth Z is shown in Formula (3):

$$Z = \frac{fK}{d}.$$
 (3)

Similarly, X and Y of point P are shown in Formula (4):

$$X = \frac{fX_L}{d}, Y = \frac{fY_L}{d}.$$
 (4)

3.1.2. Coordinate Conversion of Binocular Vision Teaching System. Binocular vision teaching system mainly includes robot, binocular vision module, and hand-held teaching device. There are five coordinate systems: BCS (robot base coordinate system), TCS (robot end-holding tool coordinate system), CCS (binocular vision coordinate system), SCS (black and white checkerboard coordinate system), and PCS (hand-held teaching device terminal coordinate system) [12]. Among them, BCS is the coordinate system constructed from the center position of the base of the robot body, which is also the reference coordinate system of the robot movement. TCS is a coordinate system with the origin of the end point of the tool held by the robot; CCS is a coordinate system constructed from the optical center of the left camera in the binocular vision system. SCS is constructed by combining the geometric relations between the inner corners of the black and white checkerboard. PCS is a coordinate system with the origin of the end point of the position and pose measuring rod of the hand-held teaching device [13]. T5 is the pose transformation from BCS to PCS, as shown in Formula (5):

$$T_5 = T_1 \cdot T_2 \cdot T_3 \cdot T_4. \tag{5}$$

 T_1 is the position and pose transformation relationship between BCS and TCS; T_2 is the position and pose transformation relationship from TCS to CCS, that is, the hand-eye relationship. T_3 is the position and pose transformation relationship from CCS to SCS. T_4 is the position and pose transformation relationship from SCS to PCS [14].

According to T_5 , the position and posture information of the end of the position and posture measuring rod (i.e., teaching point) of the hand-held teaching device can be



FIGURE 2: X, Y, Z deflection error.

 TABLE 2: Recurrence error after moving demonstration.

Teaching point	$\Delta X/mm$	Δ Y/mm	$\Delta Z/\mathrm{mm}$	$\Delta d/mm$
5	0.56	1.60	0.50	1.372 042
7	0.10	1.15	0.25	1.533 786
11	1.60	0.02	0.10	2.320 108
12	0.30	1.75	0.50	2.232 151
15	1.25	0.10	0.20	1.767 371
17	1.50	0.70	0.05	1.930 026
19	1.50	1.50	1.20	1.181 101
20	1.00	1.60	0.30	2.048 17
21	1.75	1.10	0.50	1.836 437
25	1.20	1.30	0.20	1.619 907

obtained under BCS, which can be used for the subsequent realization of the position and posture reproduction of teaching point.

3.2. Calibration of Parameters of Hand-Held Teaching Device. The hand-held teaching device contains two coordinate systems, SCS and PCS, respectively. The purpose of calibration is to determine the position and pose transformation relationship T_4 between SCS and PCS. If the design size is directly used to determine the rotation and translation transformation relationship between the two coordinate systems, there will be a large error [15]. Therefore, a translation vector calibration method from SCS to PCS was proposed, and T_4 was calculated based on the design rotation Angle from SCS to PCS (0~90). The calibration steps were as follows: Step 1. Obtain the three-dimensional coordinate information of the corner points of the visual calibration plate: the visual calibration plate is placed tiled in the effective field of view of binocular vision, and the three-dimensional coordinate information of all corners of the visual calibration plate in the binocular vision coordinate system is calculated and obtained;

Step 2. Solve T_3 : randomly select multiple corner points (at least 3) on the visual calibration board, align the ends of the hand-held teaching device with the selected corner points in turn, and collect the black and white checkerboard images on the hand-held teaching device. Corner information of black and white checkerboard was calculated, and T_3 was obtained by constructing pose matrix principle with three-point method.

The black and white checkered board has three inner corner points, respectively, P_1 , P_2 , and P_3 ; the coordination record under CCS P_1 , P_2 , and P_3 is recorded as $P_1(x_1, y_1, z_1)$, $P_2(x_2, y_2, z_2)$, and $P_3(x_3, y_3, z_3)$. The space vector under CCS is constructed according to the space coordinates of three points, with point P_1 as the common point, and points P_2 and points P_3 , respectively, form vectors, and the two vectors are perpendicular to each other to form the X-Y axis of SCS, as shown in Formula (6) and (7). The Z-axis is determined according to the right rectangular coordinate system, as shown in Formula (8).

$$\boldsymbol{X}_{w} = (x_{2} - x_{1}, y_{2} - y_{1}, z_{2} - z_{1}), \qquad (6)$$

$$\boldsymbol{Y}_{w} = (x_{3} - x_{1}, y_{3} - y_{1}, z_{3} - z_{1}), \tag{7}$$



FIGURE 3: Position error of 25 points before and after moving demonstration.



FIGURE 4: Mean error of 25 points before and after moving demonstration.

$$\boldsymbol{Z}_{w} = \boldsymbol{X}_{w} \times \boldsymbol{Y}_{w} = \begin{bmatrix} (y_{2} - y_{1})(z_{3} - z_{1}) - (y_{3} - y_{1})(z_{2} - z_{1}) \\ (x_{3} - x_{1})(z_{2} - z_{1}) - (x_{2} - x_{1})(z_{3} - z_{1}) \\ (x_{2} - x_{1})(y_{3} - y_{1}) - (x_{3} - x_{1})(y_{2} - y_{1}) \end{bmatrix}^{T}.$$
(8)

The vector X_w, Y_w, Z_w is transformed to unit vector, and the rotation matrix R of SCS relative to CCS is established as shown in Formula (9):

$$\boldsymbol{R} = [\boldsymbol{X}_{w}^{c} \boldsymbol{Y}_{w}^{c} \boldsymbol{Z}_{w}^{c}] = \begin{bmatrix} \boldsymbol{X}_{we} \cdot \boldsymbol{X}_{c} & \boldsymbol{Y}_{we} \cdot \boldsymbol{X}_{c} & \boldsymbol{Z}_{we} \cdot \boldsymbol{X}_{c} \\ \boldsymbol{X}_{we} \cdot \boldsymbol{Y}_{c} & \boldsymbol{Y}_{we} \cdot \boldsymbol{Y}_{c} & \boldsymbol{Z}_{we} \cdot \boldsymbol{Y}_{c} \\ \boldsymbol{X}_{we} \cdot \boldsymbol{Z}_{c} & \boldsymbol{Y}_{we} \cdot \boldsymbol{Z}_{c} & \boldsymbol{Z}_{we} \cdot \boldsymbol{Z}_{c} \end{bmatrix}.$$
(9)

Finally, the point coordinate value (x_1, y_1, z_1) is set as the origin of the coordinate system of the feature recognition unit, that is, the translation vector of the coordinate system. Finally, the pose transformation matrix T_3 between CCS and SCS is constructed as shown in Formula (10):

$$T_{3} = \begin{bmatrix} X_{we} \cdot X_{c} & Y_{we} \cdot X_{c} & Z_{we} \cdot X_{c} & x_{1} \\ X_{we} \cdot Y_{c} & Y_{we} \cdot Y_{c} & Z_{we} \cdot Y_{c} & y_{1} \\ X_{we} \cdot Z_{c} & Y_{we} \cdot Z_{c} & Z_{we} \cdot Z_{c} & z_{1} \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$
 (10)

Step 3. Solve T_4 : set the translation vector from SCS to PCS under CCS as T_q , as shown in Formula (11):

$$\boldsymbol{T}_{g} = \boldsymbol{T}_{3} \cdot \boldsymbol{T}_{t} = \begin{bmatrix} x \cdot R_{11} + y \cdot R_{12} + z \cdot R_{13} + x_{g} \\ x \cdot R_{21} + y \cdot R_{22} + z \cdot R_{23} + y_{g} \\ x \cdot R_{31} + y \cdot R_{32} + z \cdot R_{33} + z_{g} \\ 1 \end{bmatrix}.$$
(11)

The translation vector $[x y z]^T$ from SCS to PCS on the hand-held teaching device is denoted as Formula T_t (11), which is equivalent to Formula (12):

$$\begin{bmatrix} R_{11} & R_{12} & R_{13} & x_{gi} \\ R_{21} & R_{22} & R_{23} & y_{gi} \\ R_{31} & R_{32} & R_{33} & z_{gi} \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x_{ni} \\ y_{ni} \\ z_{ni} \end{bmatrix}.$$
 (12)

i represents the number of calibration points used for calibration, and $i \ge 3$; $[x_{ni} y_{ni} z_{ni}]^T$ is the location of the corresponding standard point in the CCS. Substitute the position information of the *i* standard points under CCS into Equation (12) and get Formula (13):

$$\begin{bmatrix} R_{11}^{i} & R_{12}^{i} & R_{13}^{i} \\ R_{21}^{i} & R_{22}^{i} & R_{23}^{i} \\ R_{31}^{i} & R_{32}^{i} & R_{33}^{i} \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} x_{n1} - x_{g}^{i} \\ y_{n1} - y_{g}^{i} \\ z_{n1} - z_{g}^{i} \end{bmatrix}.$$
 (13)

The matrix is obtained by least square method $[x y z]^T$. The rotation relationship between SCS and PCS determines the rotation matrix R_t , which performs a rotation transformation with rotation angle of 45 along the *Y*-axis of the SCS when building PCS. Then, R_t is shown in Formula (14):

$$\boldsymbol{R}_{t} = \begin{bmatrix} \cos 45^{\circ} & 0 & \sin 45^{\circ} \\ 0 & 1 & 0 \\ -\sin 45^{\circ} & 0 & \cos 45^{\circ} \end{bmatrix}.$$
 (14)

Eventually,
$$T_4$$
 is obtained by $\begin{bmatrix} R_t & T_t \\ 0 & 1 \end{bmatrix}$.

3.3. *Experimental Verification*. The experimental platform of binocular vision teaching system was set up, including the binocular vision module of Kawasaki RS010NA industrial robot, for teaching repetition test [16]. Visual system parameters are shown in Table 1.

The robot rapid teaching system with binocular vision shows the teaching process: (1.) switch to the desired trajectory fitting mode by pressing the button; (2.) in the effective field of view of binocular vision module, the hand-held teaching device is operated to align with the set point and teach the position and posture of the set point; (3.) the binocular vision system captures the image of the hand-held teaching device during teaching, calculates the position and pose information of the end of the position and pose measuring rod, and converts the position and pose information to BCS to form the robot motion path information; (4.) according to the selected trajectory fitting mode and teaching point information, the path planning is carried out to form the robot movement code and control the robot to reproduce teaching, so as to complete the rapid teaching of the robot. In addition, in the case of teaching requirements beyond the visual field range of the visual system or in order to reduce the impact of low teaching accuracy caused by large distortion of the edge of the visual field, the handheld teaching device can be moved to a new position by operating the robot to teach in the center of the visual field of vision [17, 18].

4. Result and Analysis

Select a teaching point in the space, use a hand-held teaching device to aim at the set point for teaching, and then use a robot to reproduce the teaching position and posture. The specific process is as follows:

25 points were selected in the space, and they were arranged from close to the center of the camera's field of view to far from the center of the camera's field of view, and marked $asQ_i(i = 1, 2, \dots, 25)$. Use the hand-held teaching device to align Q_i and record the terminal position information $X_i Y_i Z_i$ displayed by the upper computer of the robot; then, the robot is used for teaching and reproducing, and the error between the robot's reproducing position and teaching point position is measured [19, 20]. The diameter of the robot end welding wire is 1.2 mm, the center of the welding wire is taken as the robot end point, and the feeler gauge is used to measure the error, as shown in Figure 2.

The average distance error between the position XYZ of the teaching point and the position X'Y'Z' of the robot is 2.427 mm, which shows that the principle of binocular vision teaching system is correct [21]. At the same time, the experimental results show that the set point position near the camera's field of vision has a small reoccurrence error, while the set point position far from the camera's field of vision has a large reoccurrence error, which is caused by camera distortion [22, 23]. Therefore, it is proposed to use mobile teaching to conduct a second test on the set point (10 points) with large error to reduce the influence of camera distortion on the experimental results. By moving the robot position, the hand-held teaching device is placed in the center of the camera's field of vision and the teaching is repeated. The results are shown in Table 2.

As shown in Figures 3 and 4, by comparing the test results of the fixed teaching demonstration with the mobile teaching demonstration with the robot moving, it can be seen that the position error of the 25 points after the mobile teaching is significantly decreased: The *x*-direction mean error decreased by 10.7%, *y*-direction mean error decreased by 36.7%, *Z*-direction mean error decreased by 22.1%, and mean position error decreased by 25.3%. The experimental results show that mobile teaching has certain optimization effect on the teaching repetition accuracy and can reduce the influence caused by camera distortion [24, 25].

5. Conclusion

This paper presents the application of virtual reality technology in the teaching and training system of processing industrial robots and proposes a robot fast teaching system based on binocular vision. The experimental results show that the average error of robot teaching position is 2.427 mm after fast visual teaching. After mobile teaching, the average position error decreases by 25.3%. The system is feasible, and mobile teaching can improve the reproducibility accuracy. A hand-held teaching device is designed to simulate the real welding torch and complete parameter calibration based on the least square method to solve the problem that the current teaching tool method is not universal. The hand-held teaching device can make full use of man hands' flexibility to quickly and intuitively confirm the position and pose information of the teaching point and reduce the teaching time required by industrial robots.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no competing interests.

References

- N. Montes, N. Rosillo, M. C. Mora, and L. Hilario, "A novel real-time matlab/simulink/lego ev3 platform for academic use in robotics and computer science," *Sensors*, vol. 21, no. 3, p. 1006, 2021.
- [2] R. Ortt, C. Stolwijk, and M. Punter, "Implementing industry 4.0: assessing the current state," *Journal of Manufacturing Technology Management*, vol. 31, no. 5, pp. 825–836, 2020.
- [3] Z. Wang, "Design and implementation of polishing and polishing flexible workstation based on industrial robot," *International Core Journal of Engineering*, vol. 6, no. 4, pp. 193–197, 2020.

- [4] L. Zhang, "Evaluation and simulation of sports balance training and testing equipment based on medical video image analysis," *IEEE Sensors Journal*, vol. 20, no. 20, pp. 12005–12012, 2020.
- [5] C. Liu, D. Tang, H. Zhu, and Q. Nie, "A novel predictive maintenance method based on deep adversarial learning in the intelligent manufacturing system," *IEEE access*, vol. 9, pp. 49557–49575, 2021.
- [6] V. A. Maslivetc, J. Clair, and A. Kornienko, "Three-component assembly of stabilized fluorescent isoindoles," *RSC Advances*, vol. 12, no. 11, pp. 6947–6950, 2022.
- [7] K. Badillo-Urquiola, Z. Shea, Z. Agha, I. Lediaeva, and P. Wisniewski, "Conducting risky research with teens," *Proceedings of the ACM on Human-Computer Interaction*, vol. 4, no. CSCW3, pp. 1–46, 2021.
- [8] B. Egliston and M. Carter, "The material politics of mobile virtual reality: oculus, data, and the technics of sensemaking," *Convergence: The International Journal of Research into New Media Technologies*, vol. 28, no. 2, pp. 595–610, 2022.
- [9] M. A. Arfaoui, M. D. Soltani, I. Tavakkolnia et al., "Invoking deep learning for joint estimation of indoor lifi user position and orientation," *IEEE Journal on Selected Areas in Communications*, vol. 39, no. 9, pp. 2890–2905, 2021.
- [10] Z. Li, S. Li, and X. Luo, "An overview of calibration technology of industrial robots," *IEEE/CAA Journal of Automatica Sinica*, vol. 8, no. 1, pp. 23–36, 2021.
- [11] T. Lyu, "A control method for sma robotic actuators," *Journal of Computer and Communications*, vol. 10, no. 5, pp. 103–112, 2022.
- [12] Y. Han, J. Wu, C. Liu, and Z. Xiong, "An iterative approach for accurate dynamic model identification of industrial robots," *IEEE Transactions on Robotics*, vol. 36, no. 5, pp. 1577–1594, 2020.
- [13] J. Ang, "Scaffolded inverse blended learning: an approach to teach an online general chemistry course," *Journal of Chemical Education*, vol. 97, no. 9, pp. 2839–2844, 2020.
- [14] Q. Ouyang, S. Fan, Y. Wang, X. Lang, and C. Yu, "Enhanced methane production efficiency with in situ intermittent heating assisted CO2 replacement of hydrates," *Energy & Fuels*, vol. 34, no. 10, pp. 12476–12485, 2020.
- [15] Z. Zhang and Z. Yan, "An adaptive fuzzy recurrent neural network for solving the nonrepetitive motion problem of redundant robot manipulators," *IEEE Transactions on Fuzzy Systems*, vol. 28, no. 4, pp. 684–691, 2020.
- [16] G. P. Pochanin, L. Capineri, T. D. Bechtel et al., "Measurement of coordinates for a cylindrical target using times of flight from a 1-transmitter and 4-receiver uwb antenna system," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 58, no. 2, pp. 1363–1372, 2020.
- [17] D. Wang, H. Sun, W. Lu et al., "A novel binocular vision system for accurate 3-d reconstruction in large-scale scene based on improved calibration and stereo matching methods," *Multimedia Tools and Applications*, vol. 81, no. 18, pp. 26265– 26281, 2022.
- [18] S. C. Akkaladevi, M. Plasch, M. Hofmann, and A. Pichler, "Semantic knowledge based reasoning framework for human robot collaboration," *Procedia CIRP*, vol. 97, no. 5, pp. 373– 378, 2021.
- [19] G. Onofrei and P. Ferry, "Reusable learning objects: a blended learning tool in teaching computer aided design to engineering

undergraduates," International Journal of Educational Management, vol. 34, no. 10, pp. 1559–1575, 2020.

- [20] S. Ibaraki, K. Fukuda, M. M. Alam et al., "Novel six-axis robot kinematic model with axis-to-axis crosstalk," *CIRP Annals*, vol. 70, no. 1, pp. 411–414, 2021.
- [21] A. Sharma and R. Kumar, "Risk-energy aware service level agreement assessment for computing quickest path in computer networks," *International Journal of Reliability and Safety*, vol. 13, no. 1/2, p. 96, 2019.
- [22] P. Ajay, B. Nagaraj, and J. Jaya, "Bi-level energy optimization model in smart integrated engineering systems using WSN," *Energy Reports*, vol. 8, pp. 2490–2495, 2022.
- [23] J. Chen, J. Liu, X. Liu, X. Xu, and F. Zhong, "Decomposition of toluene with a combined plasma photolysis (cpp) reactor: influence of uv irradiation and byproduct analysis," *Plasma Chemistry and Plasma Processing*, vol. 41, no. 1, pp. 409–420, 2021.
- [24] R. Huang, P. Yan, and X. Yang, "Knowledge map visualization of technology hotspots and development trends in China's textile manufacturing industry," *IET Collaborative Intelligent Manufacturing*, vol. 3, no. 3, pp. 243–251, 2021.
- [25] H. Xie, Y. Wang, Z. Gao, B. Ganthia, and C. Truong, "Research on frequency parameter detection of frequency shifted track circuit based on nonlinear algorithm," *Nonlinear Engineering*, vol. 10, no. 1, pp. 592–599, 2021.