LABELLING ROBOTS SELECTION BASED ON AHP AND TOPSIS

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To achieve the automatic labelling on the reinforcement end surfaces of bundles for the steel plants, three different kinds of industrial robots are selected as the labelling robots based on analyzing the process technology of automatic labelling on the reinforcement end surfaces of bundles. The evaluation indexes are determined according to the requirement of automatic labelling and the application performance of labelling robots, the weight of each evaluation index is determined and the weight normalization matrix is established by analytic hierarchy process (AHP) method. According to the weight normalization matrix, the ideal solution and the negative ideal solution are determined, and the distance between object of evaluation and the ideal solution and the negative ideal solution are calculated. Eventually, the relative closeness of positive ideal solutions is calculated and the optimization scheme of labelling robots is selected by the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). This scheme can provide the guidance for the selection of industrial robots in the automatic labelling on the reinforcement end surfaces of bundles, and provide a certain reference in the selection of industrial robots for other occasions.

Keywords: Multi-criteria decision making; industrial robots; TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution); AHP (Analytic Hierarchy Process)

1. Introduction

With the development and progress of related technologies, robotic technology has developed rapidly [1]. The wide application of industrial robots can effectively alleviate the difficulties of labor in the current factory. It not only solves the problems of transformation and upgrading of the current steel plant, improves the overall automation level, but also reduces production costs and improves competition. The ability to use industrial robots in the factory has a strong practical significance. With the rapid development of industrial robots, there are more and more types and models of industrial robots [2]. The different types of robots have

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different emphasis. For example, parallel robots are more focused on speed, and tandem robots are more focused on flexibility, so the appropriate industry is selected. The robot selection is very important [3]. The reasonable selection of the labelling robot directly affects the normal and smooth operation of the automatic labelling system. Therefore, the selection of the labelling robot is based on the visual automatic labelling system for bundled round steel end faces.

Since the concept of industrial robots has been proposed, industrial robots have been continuously developed. According to the structural classification, industrial robots can be divided into five basic coordinate robots [4]: Cartesian coordinates, cylindrical coordinate robots, spherical coordinate robots, joint coordinate robots, and planar joint robots. In this topic, two types of industrial robots, a Cartesian coordinate robot and a joint coordinate robot, are initially selected considering the actual needs of automatic labelling. Among them, the Cartesian coordinate robot has three moving joints, and its end can move linearly along the X, Y and Z coordinate axes of the Cartesian coordinate system. The Cartesian coordinate robot has high reliability, high speed and high precision. Advantages of the articulated robot has multiple rotating joints that can form a relatively complex working area in space.

By analyzing the process parameters of the automatic labelling system, the three types of industrial robots with different types and different types of requirements were selected for the visual selection of the automatic labelling system for bundled round steel end faces. They are: ABB’s IRB360 parallel robot, Universal Robots’ UR5 tandem robot and BAHR’s Cartesian robot. These three industrial robots can be built to meet the requirements of the bundled round steel end face automatic labelling system, but these three robots have their own advantages, such as the series robot UR5 has great advantages in flexibility, parallel robot stiffness is greater , has a higher speed of movement [5, 6]. Therefore, it is necessary to optimize the three labelling robots to achieve the best automatic labelling of the bundled round steel end faces.

Considering the objective factors such as overall cost, accuracy, speed and labelling requirements, as well as the difficulty of programming, human-computer interaction, service and other subjective factors [7], the evaluation criteria for labelling robot selection are given, and the Analytic Hierarchy Process (AHP) is used. The evaluation criteria are weighted, the industrial robots are sorted by the TOPSIS method, and the labelling robot is finally selected. The method of AHP and TOPSIS is feasible for multiple scheme selection [8].

2. Methods

AHP is a hierarchical and systematic analysis method widely used in many fields such as medical care, transportation, energy distribution, and environmental protection [9-11]. The main method of analytic hierarchy decision making problem is stratification, using paired comparison method [12] and 1-9 comparison scale to construct paired comparison matrix for evaluation indexes, calculate weight vector and combination weight vector and do consistency test, if test by using the values of the combined weight vector to sort, and then making decisions. The specific steps of the AHP are:

(1) Determine the hierarchical structure model through evaluation indexes.

(2) Starting from the second layer, using the 1-9 comparison scale and the paired comparison method to construct a paired comparison index for each layer of evaluation indexes [13].

(3) Calculate the maximum eigenvalue λ of the paired comparison matrix and the eigenvector ω corresponding to the largest eigenvalue, and calculate the consistency index *CI* of the paired comparison matrix. The calculation formula of the consistency index *CI* is:

$$CI = \frac{\lambda - n}{n - 1} \tag{1}$$

Where λ represents the largest eigenvalue corresponding to the paired comparison matrix, and n represents the order of the paired comparison matrix.

The formula for calculating the random consistency ratio *CR* is:

$$CR = \frac{CI}{RI} \tag{2}$$

Where *RI* is called the average random consistency index, the value of *RI* can be obtained by Table 1 [13].

Table 1

Average random consistency index (*RI*)

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.22	1.26	1.36	1.41	1.46

The value of *CR* is compared with 0.1. If *CR*<0.1, the consistency test is used. The normalized value of the eigenvector corresponding to the largest eigenvalue of the paired comparison matrix is the weight vector. Otherwise, the consistency test is not required. Rebuilding paired comparisons.

(4) Calculate the consistency of the weight vector of each evaluation index combination, and the consistency weight vector consistency test formula is:

$$CR = \frac{a_1 CI_1 + a_2 CI_2 + \cdots + a_i CI_i + \cdots + a_n CI_n}{a_1 RI_1 + a_2 RI_2 + \cdots a_i RI_i + \cdots + a_n RI_n} \tag{3}$$

Where CI_i is the i-th consistency indicator of the previous layer, CI_i is the i-th average random consistency index of the previous layer, and a_i is the weight of the i-th evaluation index of the previous layer.

The method of conformance testing for CR is the same as above.

(5) Calculate the total weight of the hierarchy, and use the total weight of the hierarchy to sort, and make the final decision according to the sorting result.

Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) can objectively evaluate the multi-standard decision-making problems [14-16], which significantly improves the accuracy, applicability and scientificity of multi-standard decision-making. The TOPSIS method makes the decision by calculating the closeness of the evaluation object with the optimal solution and the worst solution. When the approximation value of the evaluation object and the ideal solution is the largest, it is optimal, and vice versa. The method of evaluating and analyzing the target using TOPSIS is as follows:

(1) Determine the evaluation indexes of the evaluation objects, score the evaluation indexes and standardize them, and construct a normalization matrix. The matrix normalization processing formula is:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{4}$$

Where x_{ij} is the value of the i-th row and the j-th column in the feature matrix.

(2) Using AHP, entropy, Delphi method and other methods to determine the weight of the evaluation indexes, and weighting the normalization matrix to construct a weight normalization matrix. The matrix weighting formula is:

$$v_{ij} = \omega_{ij} r_{ij} \tag{5}$$

Where ω_{ij} is the weight of the j-th evaluation index of the i-th layer, and r_{ij} is the value of the i-th row and the j-th column of the normalized feature matrix.

(3) Determine the ideal solution A^+ and the inverse ideal solution A^- according to the weighted normalization matrix. The formulas for determining the ideal solution and the inverse ideal solution are:

$$A^+ = (\max v_{ij} \mid j \in J_1), (\min v_{ij} \mid j \in J_2), j = 1, 2, \ldots, n, \tag{6}$$

$$A^- = (\min v_{ij} \mid j \in J_1), (\max v_{ij} \mid j \in J_2), j = 1, 2, \ldots, n \tag{7}$$

Among them, J_1 is the benefit index and J_2 is the cost index.

The distance S^+ between each evaluation target and the ideal solution A^+ and the inverse ideal solution A^- are calculated. The calculation formulas for S^+ and S^- are:

$$S^{+} = \sqrt{\sum_{j=1}^{n} (V_{ij} - A_j^{+})^2} \tag{8}$$

$$S^{-} = \sqrt{\sum_{j=1}^{n} (V_{ij} - A_j^{-})^2} \tag{9}$$

In the formula, V_{ij} represents the *j*-th evaluation index of the *i*-th evaluation target, and represents the ideal solution of the *j*-th evaluation index, and represents the inverse ideal solution of the *j*-th evaluation index.

Determine the closeness of each evaluation index and the ideal solution C^+, C^+ is calculated as:

$$C_i^{+} = \frac{S_i^{-}}{S_i^{+} + S_i^{-}} \tag{10}$$

The evaluation objects are sorted by the closeness C^+ value, and the final result of the ranking is used to make the final decision.

3. Labelling process parameters and labelling scheme

According to the production process of high-quality round steels, the automatic labelling of the bundled round steel end surfaces is arranged in the last station. The main parameters of the automatic labelling process are as follows:

Round steel diameter range: 30-110mm;

The diameter of the round steel bundle: less than 360mm;

The axial maximum distance of each round steel end surface in the round steel bundle: 50mm;

Label form and size: round labels with diameters 25mm, 40mm, 50mm, and 90mm;

Allowable labelling time per bundle of round steel: 7 min.

The automatic labelling system for bundled round steels mainly includes: machine vision unit, label preparation unit, pressure supply unit, labelling robot and control unit. By analyzing the process parameters of bundled round steel labelling, three types of industrial robots were initially selected: ABB’s IRB360 parallel robot, Universal robots’ tandem robot UR5 and BAHR’s Cartesian robot. The labelling schemes are shown in Figs. 1, 2 and 3.

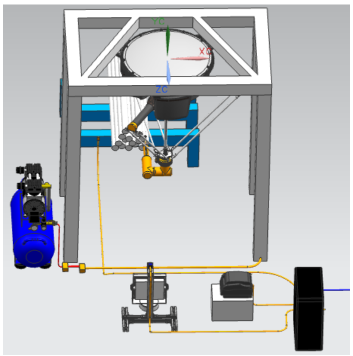

Fig. 1. Parallel robot labelling scheme

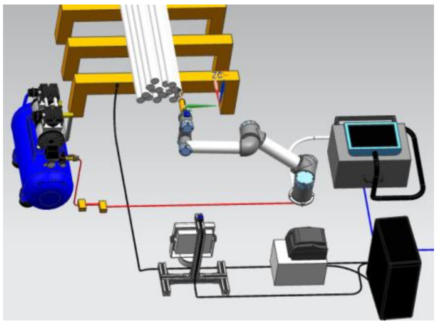

Fig. 2. Tandem robot labelling scheme

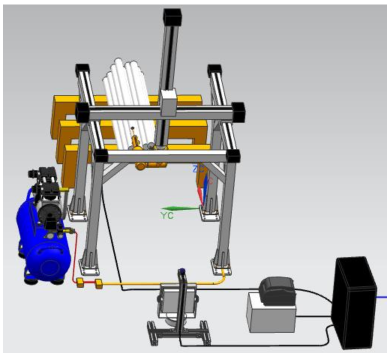

Fig. 3. Cartesian robot labelling scheme

The tandem robot UR5 has 6 degrees of freedom (DOF), the parallel robot IRB360 has 4 DOF, and the Cartesian robot has 3 DOF. The automatic labelling of the end surfaces of the bundled round steels requires at least 3 translations DOF and 2 rotational DOF. When the axis direction of the bundled round steels is parallel to the direction of motion of a cartesian-coordinate robot, it can be reduced to 4 DOF. It can be seen that the freedom of the serial robot meets the application requirements and is redundant with 1 DOF. Parallel robots require an additional 1 rotational DOF on the end effector. If the bundle of round steel is placed in a defined position, the Cartesian robot needs to add an additional DOF to the end effector. In addition, in order to facilitate the automatic labelling of the round steel end surfaces, a vacuum suction cup with a certain sliding stroke is added at the end of the labelling robot, so that the movement of the labelling robot can be simplified when the uneven round steel end surface is pasted. The labelling robot end operators are shown in Fig. 4.

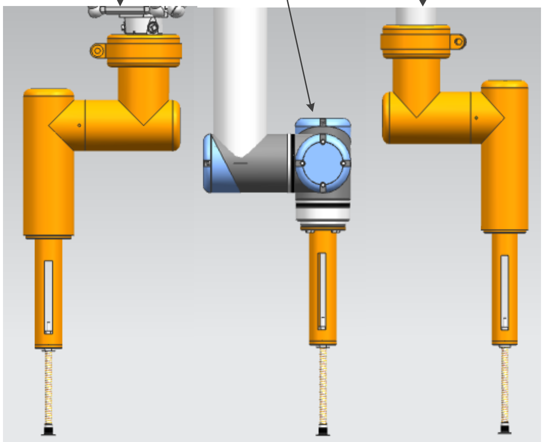

Fig. 4. End configuration of the labelling robots

According to the end configuration of the labelling robot, the tandem robot only needs to add a vacuum chuck with a certain sliding stroke at the end. The parallel robot and the Cartesian robot add a degree of freedom to the sliding vacuum chuck. Rotate the joint to complete the corner between the pick and label. The external configuration of the parallel robot and the Cartesian robot is complicated, and the relative cost is relatively high. The end operator needs to be additionally controlled on the basis of the control robot.

After the end of the labelling robot is determined, the working space and occupied space of the industrial robot can be calculated by analyzing the relevant parameters of the industrial robot. The working capacities of the three different industrial robots are shown in Table 2.

Table 2

Working space of the industrial robots

	Tandem robot	Parallel robot	Cartesian robot
Working space/m^3	2.5078	0.9207	3.375
Occupied space/m^3	0.0163	2.4388	5.762

4. Selection of labelling robots using AHP and TOPSIS

The weight of each evaluation index is determined by AHP method, and the evaluation object is calculated and sorted by TOPSIS method, which can optimize the optimal evaluation object and provide theoretical guidance for multi-standard decision-making. We use MATLAB as the simulation environment to implement selection of labelling robots.

When using the AHP and TOPSIS methods to select the labelling robot, the first thing to do is to determine the evaluation indexes. Considering the main and objective factors, the evaluation indexes of the labelling robots are finally determined as: cost A_1: price B_1, energy consumption B_2, external configuration B_3; fitness A_2: accuracy B_4, speed B_5, work ratio B_6 (ratio of workspace to occupied space); Programming A_3: Programming difficulty B_7. The hierarchical structure between the evaluation indexes is shown in Figure 5, and the evaluation indexes are shown in Table 3.

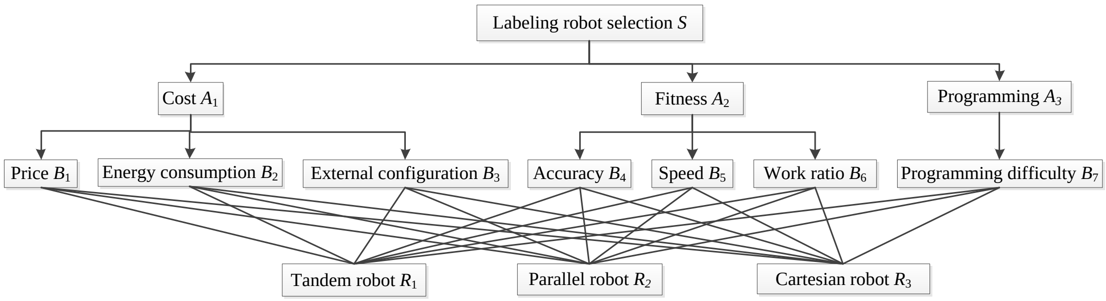

Fig. 5. Evaluation indexes hierarchy diagram

Table 3

Evaluation indexes score sheet

	Price B_1(thousand yuan)	Energy consumption B_2(kW)	External configuration B_3	Accuracy B_4(mm)	Speed B_5(m/s)	Work ratio B_6	Programming difficulty B_7
Tandem robot	198	0.2	Simple	±0.1	1	153.8528	More simple
Parallel robot	230	0.477	More complicated	±0.1	10	0.3775	Common
Cartesian robot	120	2	More complicated	±0.05	4	0.5857	Simple

The evaluation indexes in Table 3 are expressed differently, and the qualitative attributes need to be quantified. The value range of the quantized attribute value is set to 0-10, and the correspondence between the attribute level and the quantized value can be converted in the manner as shown in Table 4.

Table 4

9 level quantization table

1	2	3	4	5	6	7	8	9
Most complicated	Very complicated	complicated	Slightly complicated	Common	Slightly simple	Simple	More simple	Very simple

In the evaluation indexes, the lower the value of the price B_1, the energy consumption B_2, the external configuration B_3, the accuracy B_4, and the programming difficulty B_8, the better, which is called a cost index. The higher the value of other evaluation indexes, the better, called the benefit index. The cost index can be converted into a benefit index by: if the evaluation index is the absolute cost index *x*, then the reciprocal method (100/*x*) can be used to convert it into a benefit index; if the evaluation index is a relative cost index *x*, The difference method (10-*x*) can be used to convert it into a benefit index.

After the conversion, the value of the evaluation index is built into a feature matrix *D*, and the feature matrix is normalized by the conversion formula (4). The normalized matrix D_1 is:

$$D_1 = \begin{bmatrix} 0.4733 & 0.9183 & 0.7778 & 0.4082 & 0.0925 & 1.0000 & 0.5721 \\ 0.4075 & 0.3850 & 0.4444 & 0.4082 & 0.9245 & 0.0025 & 0.4767 \\ 0.7810 & 0.0918 & 0.4444 & 0.8165 & 0.3698 & 0.0038 & 0.6674 \end{bmatrix}.$$

After determining the normalization matrix D_1, the AHP is used to weight the feature matrix. Using the labelling comparison method and the 1-9 comparison scale to compare the second layer of evaluation indexes, the paired comparison matrix *S* is obtained, and the second layer paired comparison matrix *S* is:

$$S = \begin{bmatrix} 1 & 1/5 & 1/2 \\ 5 & 1 & 3 \\ 2 & 1/3 & 1 \end{bmatrix}.$$

It is determined that the maximum eigenvalue $\lambda_{11} = 3.0037$ of *S* can be obtained after comparing the matrix *S* and the eigenvector corresponding to the normalized maximum eigenvalue is $\omega_{11} = [0.1220, 0.6483, 0.2297]^{\mathrm{T}}$, and the consistency index *CI*=0.00175 of the paired comparison matrix can be obtained by formula (1). Looking up Table 1, we can see that the third-order paired comparison matrix average random consistency index *RI*=0.52. Using equation (2), *CR*=0.003<0.1 can be calculated, and the consistency test of the paired comparison matrix is passed. The feature vector ω_{11} corresponding to the normalized maximum eigenvalue can be used as the weight of the second layer evaluation index.

Similarly the third layer may be established three paired comparison matrix:

$$A_1 = \begin{bmatrix} 1 & 1/2 & 2 \\ 2 & 1 & 3 \\ 1/2 & 1/3 & 1 \end{bmatrix},\ A_2 = \begin{bmatrix} 1 & 1/2 & 1/7 \\ 2 & 1 & 1/4 \\ 7 & 4 & 1 \end{bmatrix},\ A_3 = [1].$$

On this basis, the maximum eigenvalue λ of the paired comparison matrix and the eigenvector ω corresponding to the largest eigenvalue of the normalized paired comparison matrix can be obtained, and the *CI* and *CR* of the paired comparison matrixes are as shown in Table 5.

Table 5

9 Layer 3 consistency test evaluation table

	A_1	A_2	A_3
ω_{21}	0.2970	0.0977	1
ω_{22}	0.5396	0.1870	1
ω_{23}	0.1634	0.7153	1
λ	3.0092	3.0020	1
CI	0.0046	0.0010	0
CR	0.0079	0.0017	0

It can be seen that the consistency ratio of the paired comparison matrixes of the third layer is $CR<0.1$, that is, the paired comparison matrix passes the consistency test, and the feature vector corresponding to the largest eigenvalue can be used as the weight of the evaluation index.

After determining the evaluation index weight vector of each layer, the consistency weight vector can be tested for consistency, and the consistency ratio of the combination weight vector is calculated by formula (3) to obtain $RI=0.003<0.1$, so the combination weight vector meets the consistency requirement, i.e. The combined weight vector can be used as the weight of the evaluation index. In this way, the weights of the standard layer and the sub-standard layer can be obtained, as shown in Table 6.

Table 6

Weight for standard layer and sub-standard layer

Evaluation index	Weights	Sub-evaluation index	Weights	Total Weights
Cost	0.1220	Price	0.2970	0.0363
		Energy consumption	0.5396	0.0659
		External configuration	0.1634	0.0199
Fitness	0.6483	Accuracy	0.0977	0.0633
		Speed	0.1870	0.1212
		Work ratio	0.7153	0.4637
Programming	0.2997	Programming difficulty	1	0.2297

The normalized matrix can be weighted by the formula (5), and the weighted normalized matrix V is:

$$V = \begin{bmatrix} 0.0172 & 0.0605 & 0.0155 & 0.0258 & 0.0112 & 0.4637 & 0.1314 \\ 0.0148 & 0.0254 & 0.0088 & 0.0258 & 0.1120 & 0.0011 & 0.1095 \\ 0.0283 & 0.0061 & 0.0088 & 0.0517 & 0.0448 & 0.0018 & 0.1533 \end{bmatrix}.$$

In the weight normalization matrix V, the vectors of the ideal solution A^+ and the inverse ideal solution A^- can be obtained by formulas (6) and (7):

$$A^+ = \begin{bmatrix} 0.0283 & 0.0605 & 0.0155 & 0.0517 & 0.1120 & 0.4637 & 0.1533 \end{bmatrix},$$

$$A^- = \begin{bmatrix} 0.0148 & 0.0061 & 0.0088 & 0.0258 & 0.0122 & 0.0011 & 0.1095 \end{bmatrix}.$$

After determining the ideal solution A^+ and the inverse ideal solution A^-, the distance between each evaluation object and the ideal solution and the inverse ideal solution can be obtained by formulas (8) and (9):

$$S^+ = \begin{bmatrix} 0.1070 & 0.4669 & 0.4700 \end{bmatrix}^T,$$

$$S^- = \begin{bmatrix} 0.4663 & 0.1027 & 0.0625 \end{bmatrix}^T.$$

Using the formula (10), the value of the closeness C^+ of each evaluation object and the ideal solution can be calculated as:

$$C^+ = \begin{bmatrix} 0.8134 & 0.1803 & 0.1173 \end{bmatrix}^T.$$

It can be seen that the preferred ordering of the labelling robot is $R_1 > R_2 > R_3$, that is, the preferred ordering scheme of the labelling robot is: tandem robot UR5, parallel robot IRB360 and Cartesian robot. The preferred result of the labelling robot is tandem robot UR5.

5. Conclusion

The selection of labelling robots is one of the key technical problems in the automatic labelling system for bundled round steel end surfaces. The quality of the selection directly affects the operation of the entire automated production line. The AHP is used to determine the weight of each preferred target. TOPSIS is used to optimize the labelling robot, which can eliminate the interference of human subjective factors to the greatest extent, and provide scientific and accurate basis for the optimization of labelling robot. This preferred decision lays the foundation for the hardware selection and construction of the bundled round steel end surfaces automatic labelling system, and has reference significance for the selection of industrial robots in other occasions. Future research focuses on further combining AHP, TOPSIS, and other scheme optimization methods to improve the rationality of scheme selection.

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R E F E R E N C E S

[1]. *E. Dean-Leon, K. Ramirez-Amaro, F. Bergner, I. Dianov, G. Cheng,* “Integration of robotic technologies for rapidly deployable robots”, IEEE Transactions on Industrial Informatics, **vol. 14**, 2018, pp. 1691-1700.

[2]. *K. Raza, T. Khan, N. Abbas,* “Kinematic analysis and geometrical improvement of an industrial robotic arm”, Journal of King Saud University - Engineering Sciences, **vol. 30**, 2018, pp. 218-223.
[3]. *R. Breaz, O. Bologa, S. Racz,* “Selecting industrial robots for milling applications using AHP”, Procedia Computer Science, **vol. 122**, 2017, pp. 346-353.
[4]. *G. Gao, H. Zhang, H. San, et al,* “Kinematic calibration for industrial robots using articulated arm coordinate machines”, International Journal of Modelling Identification and Control, **vol. 31**, 2019, pp. 16-26.
[5]. *R. Jha, D. Chablat, L. Baron, et al,* “Workspace, joint space and singularities of a family of delta-like robot”, Mechanism and Machine Theory, **vol. 127**, 2018, pp. 73-95.
[6]. *L. Feng, W. Zhang, Z. Gong, et al,* “Developments of delta-like parallel manipulators - a Review”, Robot, **vol. 36**, 2014, pp. 375-383.
[7]. *S. Narayanamoorthy, S. Geetha, R. Rakkiyappan, et al,* “Interval-valued intuitionistic hesitant fuzzy entropy based VIKOR method for industrial robots selection”, Expert Systems With Applications, **vol. 121**, 2019, pp. 28-37.
[8]. *Y.J. Huang, Y. Yan, Y. Liu, et al,* "The preferred method of labelling machines people in a kind of bundled round steel end face automatic labeling system", Chinese Patent CN106395051B.
[9]. *R. Breaz, O. Bologa, S. Racz,* “Selecting industrial robots for milling applications using AHP”, Procedia Computer Science, **vol. 122**, 2017, pp. 346-353.
[10]. *R. Breaz, O. Bologa, S. Racz,* “Selecting between CNC milling, robot milling and DMLS processes using a combined AHP and fuzzy approach”, Procedia Computer Science, **vol. 122**, 2017, pp. 796-803.
[11]. *M. Simion, L. Socaciu, O. Giurgiu, S.M. Petrisor, et al,* “The selection of industrial robots for military industry using AHP method: a case study”, ACTA Technica Napocensis Series-Applied Mathematics Mechanics and Engineering, **vol. 61**, 2018, pp. 231-240.
[12]. *P. Qin, Y. Xu, X. Zeng, et al.,* “Acoustic signal hypnotic effect research based on paired comparison”, Audio Engineering, **vol. 38**, 2014, pp. 45-53.
[13]. *P. Rajani*, “Implementation of analytic hierarchy process (AHP) as a decision support tool for selection of robot for spot welding operation”, International Journal of Research in Engineering and Technology, **vol. 5**, 2016, pp. 7-12.
[14]. *A. Shukla, P. Agarwal, R.S. Rana, R. Purohit,* “Applications of TOPSIS algorithm on various manufacturing processes: a review”, Materials Today-Proceedings, **vol. 4**, 2017, pp. 5320-5329.
[15]. *I. Igoulalene, L. Benyoucef,* “Consensus-based fuzzy TOPSIS approach for supply chain coordination: application to robot selection problem”, IFAC Proceedings Volumes, **vol. 47**, 2014, pp. 772-777.
[16]. *D. Joshi, S. Kumar,* “Interval-valued intuitionistic hesitant fuzzy Choquet integral based TOPSIS method for multi-criteria group decision making”, European Journal of Operational Research, **vol. 248**, 2016, pp. 183-191.