DESIGN OF QUICK DOCKING METHOD FOR END EFFECTOR OF INDUSTRIAL ROBOT

Haifeng ZHAO[1]*, Yan GUO[2]

In view of low replacement efficiency of the end effector of industrial robots, an auxiliary quick docking tool was designed. Through the laser transmitter, four-quadrant position detector, data collector and positioning tool for the female quick changer, quick connection is achieved between the male and female quick changer at the end of the robot. During the docking process, the laser transmitter placed at the end of the sixth axis of the robot emits a bright spot, irradiates the four quadrant position detector at the position of the cathode fast converter on the workbench, reads the position coordinate data of laser bright spot in the four quadrant position sensor. Overlay the data onto the corresponding coordinate position of the robot teaching device, and operates the robot to realize the rapid docking of the robot quick changer. The experimental test showed that the designed quick docking device had a repeated positioning accuracy of not less than 0.038mm in the horizontal plane. The use of the docking device designed herein greatly shortens the time for the robot to replace the fixture and increases the production efficiency.

Keywords: industrial robot, end quick changer, auxiliary docking tool, position detector, data acquisition

1. Introduction

Due to their flexible, reliable, and multi-task execution functions, industrial robots are widely used in abundant intelligent manufacturing fields such as electronic product assembly, automobile manufacturing, and chemical industry. In working, when the same station needs to complete different processing tasks, the robot often needs to change the end tool (effector). When there are more process requirements for the same station, the robot is equipped with more end tools. In some complex stations, the robot is equipped with a tool library composed of multiple end tools [1-5]. In order to enable rapid replacement of end tools, the existing practice is to use the male quick changer installed at the end of the robot arm, and one or more female quick changer placed on the workbench to replace them one by one through point-to-point teaching [6-9].

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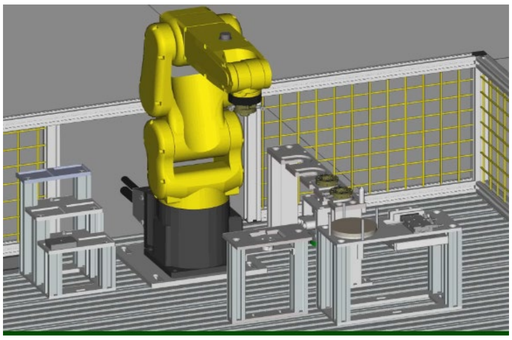
Thanks to the appearance of the end quick changer of the robot, the robot can complete different processing tasks in the same station [10-12]. However, numerous quick changers also bring inconvenience to the robot teaching operation. When it is necessary to replace different end clamps, one-by-one manual teaching at the point is needed, which causes great trouble to the new operator of the robot hand [13]. In order to address the above problems, this paper designs an auxiliary quick docking device for the end effector of the robot. Through the laser transmitter, four-quadrant position detector, data collector and positioning tool for the female quick changer, quick connection is achieved between the male and female quick changer at the end of the robot. It greatly shortens the time required for teaching the robot to change the fixture, saves the cost of production and debugging, and increases the production efficiency. The repeated positioning accuracy can reach 0.038mm.

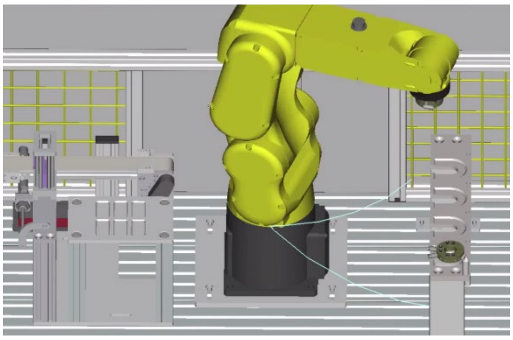
This article introduced the photoelectric four quadrant position detector for industrial robot point teaching in the first time, and developed corresponding position detection software and designed a variable diameter concave head positioning tool. The designed robot end effector assisted rapid docking device has changed the traditional point teaching method of industrial robots, providing a new and accurate docking method for rapid point teaching of industrial robots. In addition, this new docking method and device can also be extended to precise positioning of robot end fixtures for industrial robots grasping materials, moving goods, and other occasions.

2. Quick docking methods and tools

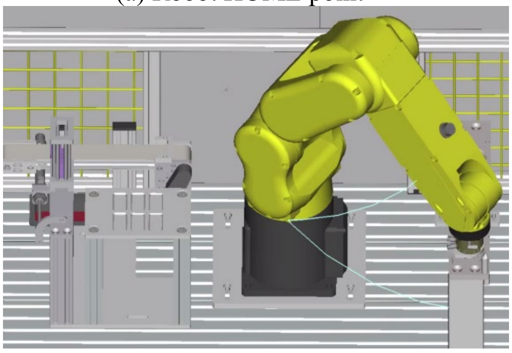
When an industrial robot needs to replace the end effector to perform a task, its operation process generally has four steps [14-15] (as shown in Figure 1): the initial HOME point of the robot → move the robot joint to the safety point above the end effector → move the robot joint to the position replacement point of the end effector → replace the end effector → return to the safety point above the robot end effector, and then start the task action execution. This replacement process has high requirements on the robot operator. A slight deviation will cause collision between the male and female end quick changer of the robot, triggering a robot collision alarm, which even leads to damage to the robot joints in severe cases and greatly reduces accuracy.



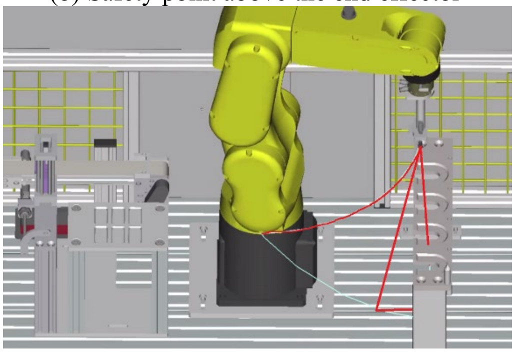
(a) Robot HOME point



(b) Safety point above the end effector



(c) End effector position point



(d) Safety point above the end effector

Fig. 1 Replacement process of robot end effector

To this end, this paper proposes an auxiliary fast docking method and device for the replacement of the robot end effector. The structure of the designed auxiliary docking device is shown in Figure 2.

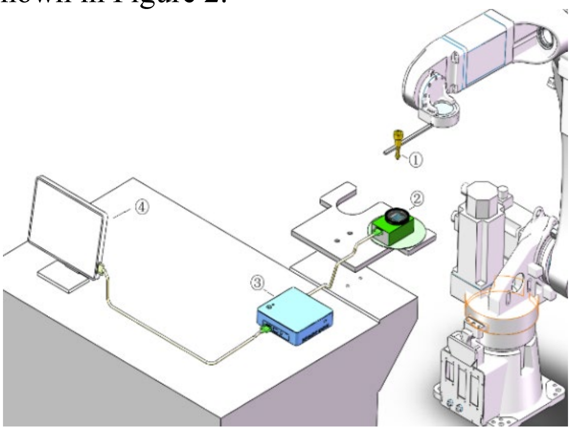


Fig. 2 Auxiliary docking device of robot end effector

Without changing the existing quick changer structure of the robot, the designed docking device adds micro laser transmitter①, four-quadrant position detector②, data acquisition unit③, display terminal④ etc. in the robot station. When there is need to replace the robot end effector, one needs to initially adjust the robot's posture above the end effector, and then emit laser light through the laser transmitter installed at the sixth joint of the robot to irradiate the sensitive panel at four-quadrant position detector on the quick changer table. The panel can measure the relative position of the male and female robot end effector in real time, collect the current position deviation data through the data acquisition unit, and then transmit it to the display terminal for display. At this time, the operator directly reads the relative deviation data of the male and female heads in the X and Y directions through the display terminal, and directly records it in the robot teach pendant to achieve quick docking of the robot end quick changer.

The above operation flow can be illustrated in Fig. 3.

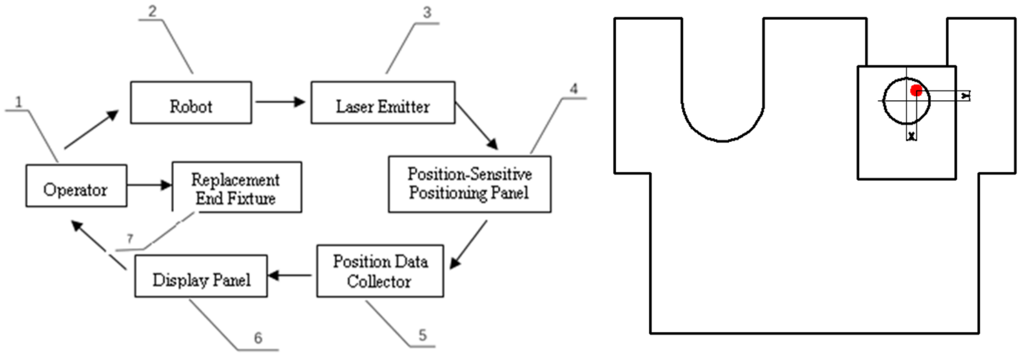


Fig. 3. The quick-change docking process of the end effector and the position deviation data in the X and Y directions

3. Docking principle and parts

3.1 Docking principle

In the above docking method, four-quadrant position detector is used to measure the relative position of the male and female quick changer. The four-quadrant detector is a constant photoelectric position detector. The entire circular detection panel is divided into four quadrants by photolithography, and each quadrant is independent of each other [15-17]. Its structure is shown in Fig. 4.

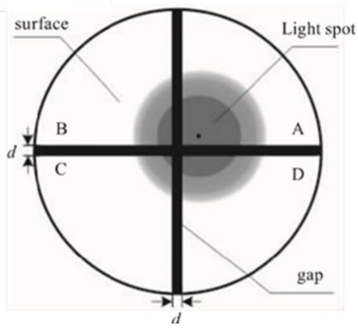


Fig. 4 Structure diagram of the four-quadrant detector

In working, when the laser transmitter emits laser light on the photosensitive surface of the four-quadrant detector, a laser spot with Gaussian distribution is formed. Due to the different positions of the spot, light of different energies is received in each quadrant, so that photovoltaic effect of each quadrant forms photocurrents of different magnitudes. It is hypothesized that the light energies received by each quadrant of the four-quadrant detector are P_A,P_B , P_C and P_D , respectively, and the currents generated by the light energy areI_A , I_B , I_C andI_D, respectively[18] .When the irradiation position changes, the optical path will also change, resulting in position change of the light spot on the photosensitive surface. At this time, the center position of the light spot can be judged by the current value of each quadrant. The spot center position is expressed as:

$$X = \frac{(P_A + P_D) - (P_B + P_C)}{P_A + P_B + P_C + P_D} = \frac{2 \times (I_A + I_D)}{I_A + I_B + I_C + I_D} \tag{1}$$

$$Y = \frac{(P_A + P_B) - (P_C + P_D)}{P_A + P_B + P_C + P_D} = \frac{2 \times (I_A + I_B)}{I_A + I_B + I_C + I_D} \tag{2}$$

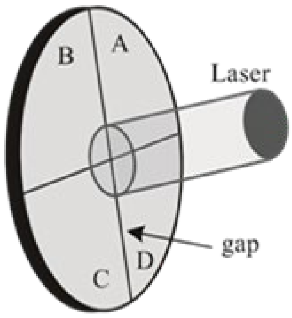


Fig. 5 Spot position of four-quadrant detector

Where (X, Y) is defined as the laser spot position estimation. The relative position of the male and female quick changer can be accurately determined by estimating the light spot position.

3.2 Docking parts

After the docking method and principle are determined, it is necessary to design and select the parts of the docking device. According to the design method herein, this section mainly completes the design and selection of laser transmitter, four-quadrant position detector, data acquisition unit, display terminal and end centering device.

1) Laser transmitter

The paper uses a 635nm red dot laser transmitter. The laser transmitter mainly emits a point-shaped light spot and projects it vertically on the photosensitive panel of the four-quadrant detector. In order to effectively measure the relative position of the male and female end quick changer, it can be fixed on the sixth axis of the robot through an auxiliary fixture or directly installed on the center cavity of the male quick changer. The structure and performance of the laser transmitter selected herein are shown in Figure 6 and Table 1.

Fig. 6 Laser transmitter

The performance parameters are shown in Table 1.

Table 1

Laser transmitter performance parameters

Contour parameter	Boundary dimension	$\Phi 9 \times 21mm$
	Shell material	(Environmental-friendly)aluminum parts
	Wire specification	26# red and black wires
Electronic parameter	Voltage range	3V-5V
	Working current	<45mA
Optical parameter	Laser wavelength	635nm
	Wavelength drift(nm/° C)	0.25nm
	Divergence angle	<0.7mrad alignment
	Spot size	Adjustable spot size
	Lens material	PMMA aspherical optics
	Output power	<10mW

2) Four-quadrant position detector

The four-quadrant position detector adopts DRX-2DPSD-OA02-X signal processing board of high-precision two-dimensional position sensor. With an effective measurement range of 15*15mm, it has high position resolution, wide spectral response range, high-speed response, simultaneous position and intensity measurement, high reliability and small size. The structure is shown in Figure 7.

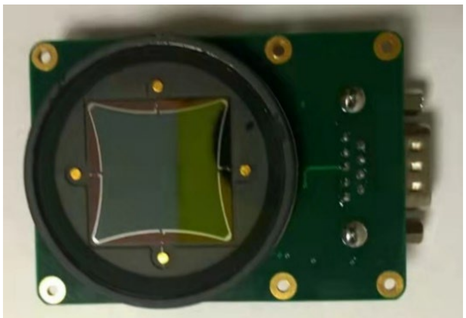


Fig. 7 Four-quadrant position detector

3) Data acquisition unit

The RX-PSD-232/485-X continuous light source signal acquisition processor is adopted as the data acquisition unit, as shown in Fig. 8. The signal processor can provide RS232, RS485, USB interface, which adopts high-speed 18-bit AD chip, and has built-in integrated high-precision position-sensitive measurement bias voltage to process one-dimensional, two-dimensional position sensor and four-quadrant detector signals.

Fig. 8 Location Data Collector

4) Display terminal

The display terminal can be an ordinary computer or a flat panel display.

5) Positioning tool for female quick changer

In order to accurately place the four-quadrant position detector at the position of the bracket where the female quick changer is located, considering that the female quick changer and the bracket are generally matched in a semicircle or a circle, a variable-diameter female head positioning tool is designed, which supports accurate installation of four-quadrant position detector.

The variable-diameter female head positioning tool consists of a support plate, a six-equal-slotted disc bracket, a central gear with a spiral groove, a star wheel, a variable-diameter cylindrical slider (6 pieces) with a cylindrical pin inside, and a handle, as shown in Fig. 9. When working, the four-quadrant position detector is placed in the center of the positioning tool of the female quick changer through the positioning bolt. Then, the variable-diameter female head positioning tool is placed above the bracket of the female quick changer (Fig. 10). The handle is rotated to boost the gear drive, the center wheel rotates and pushes the cylindrical pin to drive the variable-diameter cylindrical slider, so that the variable-diameter cylindrical radius adapts to the bracket diameter of the female quick changer, and achieves the purpose of rapid centering and positioning.

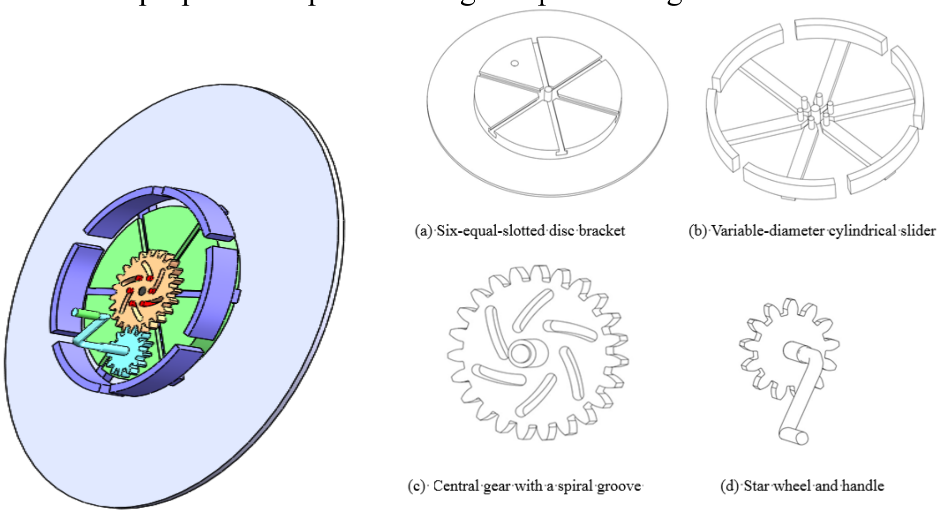


Fig. 9 Variable-Diameter Female Head Positioning Tool and Parts

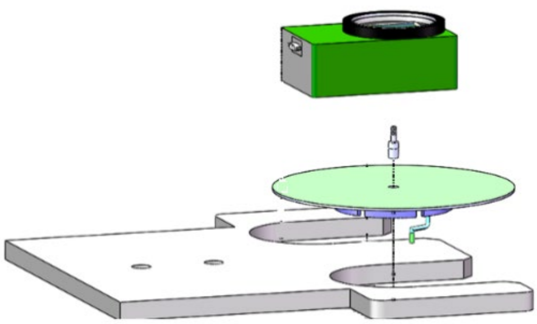


Fig. 10 Positioning Process

4. Docking experiment and repeated docking accuracy analysis

4.1 Docking experiment

The designed quick docking device is installed on the industrial robot station, as shown in Figure 11, the model of robot is ER20-1780 from China Estun Automation Group, and with repeatability of ±0.03mm.The manipulator moves the male end effector above the female head bracket of the quick changer. The laser projected by the laser transmitter installed at the male head irradiates the four-quadrant detector at the position of the quick changer to form a red light spot. At this time, the data acquisition unit collects the position deviation of the male head of the quick changer relative to the female head, and displays it on the terminal software interface through transmission. The results are shown in Fig. 12. At this point, after reading the deviation values of the male and female quick changers on the horizontal X-axis and Y-axis, the operator adds the deviation values to the displayed X-axis and Y-axis values in the robot's current position teaching interface (as shown in Fig. 13) and inputs them into the teaching device. At this time, the female head of the quick changer is put into the bracket, the robot arm continues to move in the Z direction. When the male head enters the female head port of the end tool, the robot outputs the I/O signal, and the male and female heads are butted together to complete docking of the quick changer, with result shown in Figure 14. After the successful docking, the end tool is taken out of the tool library, and the replacement process is successfully completed. The positioning terminal software used in the Windows 2007 and Microsoft .NET Framework 4.0 or above environments.

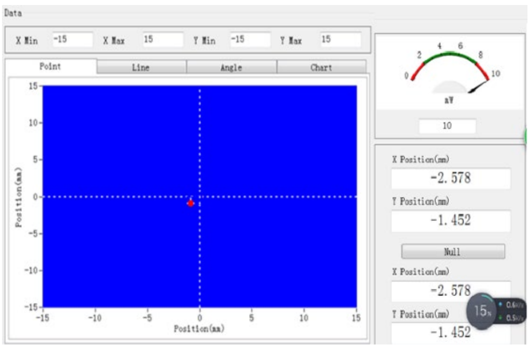


Fig. 11 Schematic diagram of docking

Fig. 12 Deviation values

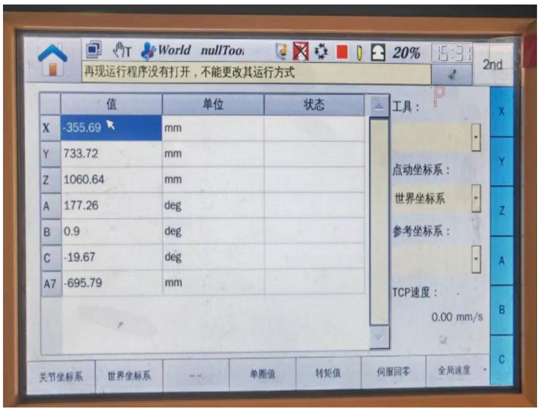


Fig. 13 Adjustment position value of teach pendant   Fig. 14 Quick changer after docking

4.2 Analysis of repeated docking accuracy

In order to verify the repeated accuracy of the docking device, the project designed an experimental verification scheme. The specific experimental steps and plans are as follows:

1) Male and female heads of a certain robot quick changer were fully docked as a standard docking reference. After that, the male and female head suction port of the quick changer was opened, the robot was lifted to a certain height in the Z direction, and laser transmitter was installed in the middle of the male head. At the same time, the center of the four-quadrant position detector was adjusted to overlap with the center of the quick changer female bracket. The X/Y/Z values were recorded under the current robot Cartesian coordinates;

2) The quick changer female bracket was taken out, and the bracket positioning tool was used to install the four-quadrant position detector in the center of the bracket;

3) After manually moving the robot away from the initial position, the above recorded X/Y/Z values were entered in the teach pendant. The motion command was executed so that the robot returned to the aforementioned initial position. The terminal X, Y deviation values were recorded and displayed;

4) Steps 2-3 were repeated several times. Data was recorded;

5) Data analysis was performed to calculate repeated positioning accuracy.

The experimental test data are shown in Table 2.

Table 2

10 times' repeated verification data

No.	X coordinate (mm)	Y coordinate (mm)	Center position offset (mm)
1	0	0	0
2	0.013	0.035	0.037
3	0.025	0.024	0.035
4	0.016	0.021	0.026
5	0.019	-0.015	0.024
6	-0.032	0.021	0.038
7	0.024	-0.021	0.032
8	0.012	0.02	0.023
9	0.015	-0.019	0.024
10	0.021	0.023	0.031

Seen from the above data analysis for different positions, in the docking level, the repeated position accuracy of the designed docking device does not exceed 0.038mm.

At the same time, according to the test time recording, the replacement of quick changer with the auxiliary docking device is nearly 2 minutes faster than that without the device under normal circumstances. In particular, for new operators, the average docking time is saved by nearly 8 minutes.

5. Conclusions

Based on the principle of four-quadrant position photoelectric detection, this paper designs an auxiliary quick docking device. Through the laser transmitter, four-quadrant position detector, data collector and positioning tool for the female quick changer, quick connection is achieved between the male and female quick changer at the end of the robot. The repeated docking accuracy of the auxiliary quick docking device was comparatively analyzed under the same benchmark in 10 experiments. In the docking horizontal plane, the repeated position accuracy of the designed docking device did not exceed 0.038mm, which verified the feasibility of the docking device and the docking method. By using the quick docking tool of industrial robot end effector designed herein, it greatly shortens the time for changing the fixture when the robot operates, and increases the production efficiency. In the future, we will investigate how to further optimize the structure miniaturization and rapid-docking repeated positioning accuracy of industrial robot end effectors.

Acknowledgments

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REFERENCES

[1] *Tang Zhidong, Yun Chao,* Technical Overview of Full Automatic Quick Changer Quick Device. Journal of Zhejiang University (Engineering Edition), **vol.51**, 2017. pp: 461-470

[2] *Liao Kunyu*, Research on Robot End-effector Exchange. Master's thesis, Southwest University of Science and Technology, 2018.

[3] *Li Na*, Design and Optimization of Robotic Tool Changer. Master's thesis, Shandong University, 2017.

[4] *Jiyun Zhang, Zhifeng Lou and Kuang-ChaoFan*, "Accuracy improvement of a 3D passive laser tracker for the calibration of industrial robots", in Robotics and Computer-Integrated Manufacturing, **vol.81**, 2023. pp: 102487-102496.

[5] *Sara Sharifzadeh, Istvan Biro and Peter Kinnell.* "Robust hand-eye calibration of 2D laser sensors using a single-plane calibration artefact", in Robotics and Computer-Integrated Manufacturing, Vol.61, 2020. pp: 101823-101831.

[6] *Masumi Ohno, Yukio Takeda*, "Design of target trajectories for the detection of joint clearances in parallel robot based on the actuation torque measurement", in Mechanism and Machine Theory, **vol. 155**, 2021.pp:104081-104100.

[7] *Zemin Cui, Guoteng Zhang, Xuewen Rong, Yibin Li,* "Design and motion planning of hydraulically driven leg for maximum height jumping", in Mechatronics, **vol. 74**, April. 2021, p.102499.

[8] *Chao Wang, Xizhe Zang, Xuehe Zhang, et al*., "Parameter estimation and object gripping based on fingertip force/torque sensors", in Measurement, **vol.179**, July. 2021,p.109479.

[9] *Cui Hang, Wu Xizhi, Deng Minya*, "Research on automatic quick changer of end actuator for furniture grinding robot", in Journal of Central South University of Forestry & Technology, **vol.37**, No.12, Dec, 2017. pp: 159-162.

[10] *Turnberg C.,* "Robot End-of-Arm Tooling: A Small Way to Make a Big Difference", in Plastics Technology, No.2, 2015.

[11] *Hwang Yeji, Lee Seongpung, Hong Jaesung*, "A Novel End-Effector Robot System Enabling to Monitor Upper-Extremity Posture During Robot-Aided Planar Reaching Movements", in IEEE Robotics and Automation Letters, No.2, 2020, pp: 3035-3041.

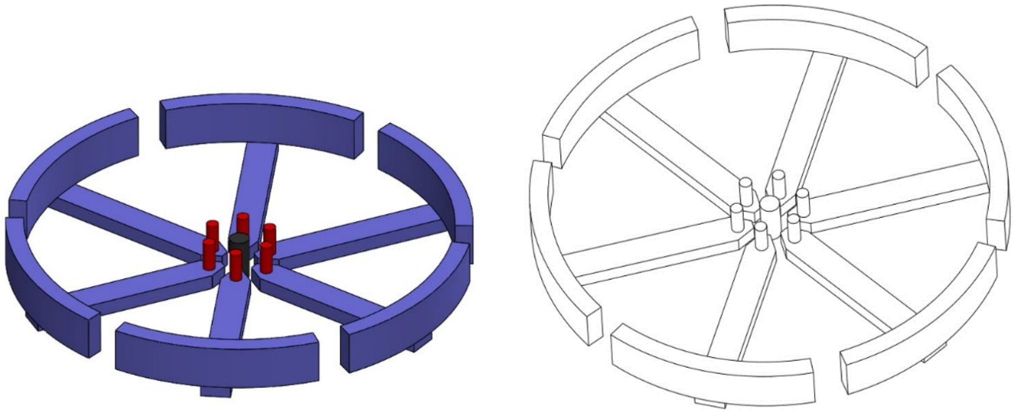
[12] *Xu Sens*en., Design and analysis of automatic tool changer in the grinding center. Master's thesis, Xiangtan University, 2014.

[13] *Liu Qikun,* Research on end tool exchange device of space robot. Master's thesis, Harbin University of Technology, 2012.

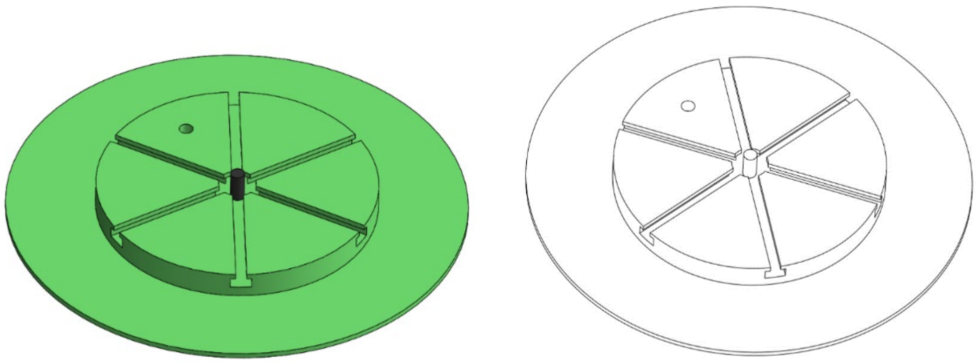
[14] *Liao Kunyu, Liu Manlu*, *Zhang Junjun, et al*., "A robot end-effector exchange device and the simulation analysis", in Manufacturing Automation, vol.40, No.8, Aug, 2018. pp: 122-126.

[15] *Xu Jingquan, Mei Tao, Luo Minzhou*. “The development of an automatic exchange device for space robot hands”, in Industrial Instrumentation & Automation, **vol.04**. 2006, pp: 13-16.
[16] *Shu Pingsheng*, “Research on Integrated Parameter Measuring Device for Deep Hole”, in Tool Technology, **vol.51, No. 06**, 2016. pp: 134-136. DOI:10.16567/j.cnki.1000-7008.2017.06.032
[17] *Chen Zhenya, Shen Xingquan, Pang Junzhong, et al*., “Photoelectric Measurement Method of Deep Hole Straightness”, in Transactions of the Chinese Society for Agricultural Machinery, **vol.45**, No. 12, 2014.pp: 362-366. DOI: 10.6041 /j. issn.1000-1298.2014. 12. 052

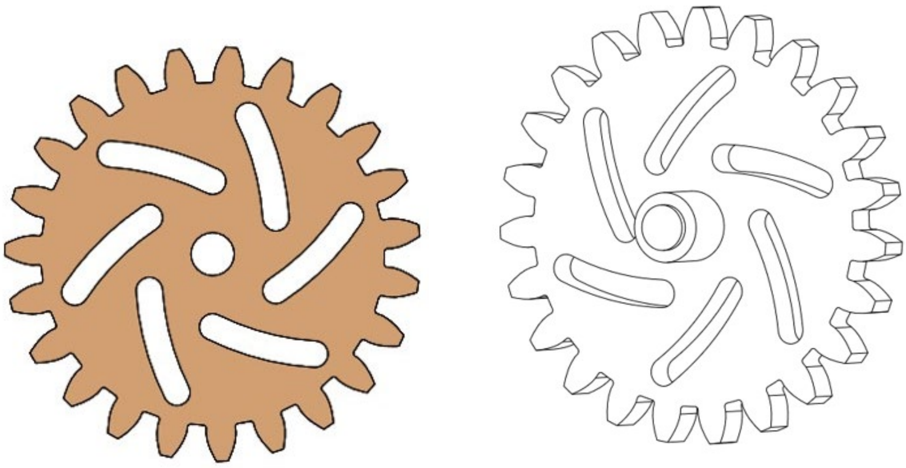
The schematic diagram of this mechanism is shown below.



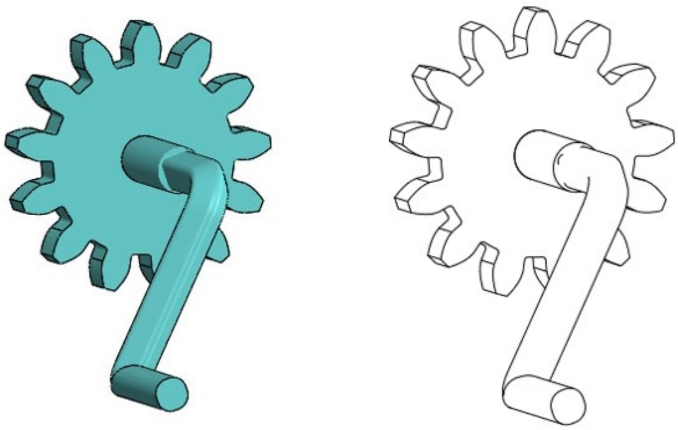
The sketch of variable-diameter cylindrical slider (6 pieces)



The sketch of six-equal-slotted disc bracket



The sketch of central gear with a spiral groove



The sketch of star wheel and handle