Research on Automatic Assembly Technology for Spacecraft System

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Abstract. With the increasing integration degree of spacecraft products in recent years, existing automated assembly technologies do not fully meet the product assembly requirements. Therefore, the level of automation of the assembly needs to be improved, and the general assembly efficiency of non-standard spacecraft components needs to be improved. Depending on the assembly requirements, integrating visual recognition, path planning, grasping functions, and flexible assembly technologies into automated assembly systems, breaking through the technical bottleneck in the automatic assembly of existing spacecraft systems. The test results show that, the automated assembly system is capable under remote operating conditions, complete the precise docking, grasping and collision-free assembly process of spacecraft products, meet the automatic assembly requirements of spacecraft products.

Keywords: Visual recognition · Path planning · Terminal actuator grab · Flexible assembly

1 Introduction

Spacecraft products serve various types, so most of the spacecraft products are specially customized, not batch, spacecraft assembly conditions are not repetitive, can not ensure the installation accuracy through the conventional teaching and reproduction mode. At present, the flexible assembly technology developed at home and abroad is an advanced assembly technology that can adapt to the rapid development and production [1]. With the continuous improvement of the integration degree of spacecraft products in recent years, the existing automatic assembly technology cannot fully meet the needs of product assembly, especially reflected in the following four aspects:

1. For large size installation parts in the cabin, it is difficult to ensure the accurate assembly in place and produce clearance or stress. For multi-hole installation conditions, it is difficult to control the installation accuracy [2];
2. For the parts installed in the spacecraft capsule, due to the limited space for human observation, it is difficult to adjust the position of the installed parts during operation, which is prone to bumps, and comes with the high risk of product damage [3];

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3. For spacecraft products with own weight limits, the product itself does not provide a mounting hole for regular threaded connections.
4. For the installation of spacecraft test equipment applied outside the space capsule, the astronauts need to leave the capsule, resulting in the corresponding high risk, physical consumption and related costs [4].

Therefore, it is necessary to improve the automation level of assembly and improve the general assembly efficiency of non-standard spacecraft components.

According to the assembly requirements of the above spacecraft system, this paper studies the automatic assembly system integrating visual recognition, path planning, grasping function and flexible assembly technology. The scheme adopted has the following advantages:

1. Improve the visual recognition accuracy, identify and locate the assembled products based on OCR technology, and plan the captured location of the products.
2. Plan the assembly path, and detect the collision-free path of the mechanical arm between the assembly start point and the assembly target point based on the RRT algorithm.
3. In order to achieve the capture and assembly of spacecraft products, use mechanical claws to grasp the product based on the principle of force sealing, and use flexible assembly technology to realize the product assembly.
4. It can operate remotely to avoid the astronauts from completing the installation of the equipment.

2 Establishment of the System

2.1 System Composition

The automatic assembly system is shown in Fig. 1, including four parts: terminal actuator system, mechanical arm system, AGV system, and integrated control system.

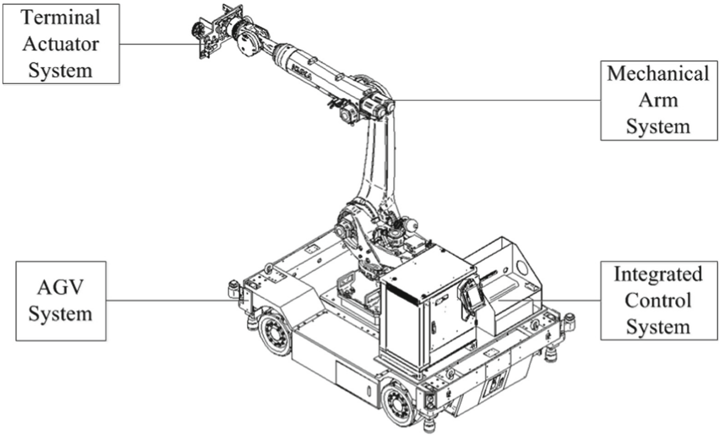

Fig. 1. The automatic assembly system

2.2 Working Principle

Through the spacecraft system assembly requirements, build consists of AGV, robotic arm system, integrated control automatic assembly system, through AGV assembly to assembly space area, through the mechanical arm assembly system attitude control operation, through the terminal actuator to grasp the object identification and data acquisition, through integrated control grasping connection calibration, teaching and scene simulation, form a multi-unit product automatic assembly mode, guarantee the assembly quality of each type of spacecraft products. The system composition diagram is shown in Fig. 2.

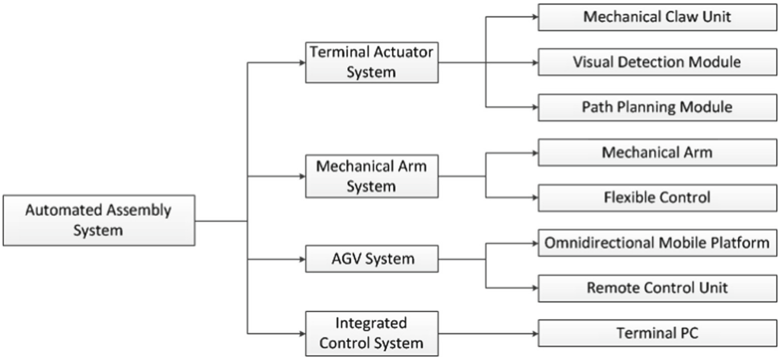

Fig. 2. The system composition diagram

3 Key Technology Applications

According to the assembly requirements, the key technologies of the end-actuator system are mainly reflected in four aspects: visual guidance and identification, path planning and obstacle avoidance, product grasping, and flexible assembly.

3.1 Visual Guidance and Recognition

Based on visual OCR and robot identification product code and number, and send the acquisition image, acquisition time and identification result information to the upper computer; guide the robot movement to the designated location, visually identify and locate the specific area on the assembly target, obtain the end of the execution and the assembly target relative space location information; automatically calculate the robot motion bias, guide the robot movement to the grab position, complete the positioning [5].

The robot drives the recognition camera motion to the specified position, through the monocular visual system, detect the artifact outline, hole and other features, after image gray, image filtering, profile extraction, edge detection, calculate the offset between the current workpiece position and the calibration position, after transformation processing sent to the robot controller, to achieve the end of the capture.

The OCR key is to convert the characters in the pictures into a text format understood by the computer. The robot is equipped with an OCR camera to move to the fixed position of the installation and parking table of the product, shoots the corresponding area of the equipment on the workbench, and extracts the attribute information such as code name and number. The object image information to be captured is obtained through the visual system, and the image containing text from the input to the final output text result is realized based on the OCR method [6].The encoding format is as follows:

$$\begin{cases} (PLN; SLN, DLN, BLN); \\ (P1, L1; P2, L2; P3, L3 \ldots P_{PLN}, L_{PLN}); \\ (P1, L1; P2, L2; P3, L3 \ldots P_{SLN}, L_{SLN}); \\ (P1, L1; P2, L2; P3, L3 \ldots P_{DLN}, L_{DLN}); \\ (P1, L1; P2, L2; P3, L3 \ldots P_{BLN}, L_{BLN}); \end{cases} \tag{1}$$

PLN represents the number of lateral line segments, SLN represents the number of longitudinal line segments, and DLN and BLN represent the number of 45° and reverse 45° angular line segments, respectively [7].

3.2 Path Planning and Obstacle Avoidance

The virtual simulation environment is constructed based on the assembly scenario, to realize the offline path planning between the artifact grab bit and the assembly bit, and to generate the robot motion path program [8].

First, the assembly environment modeling, according to the modeling results of the end of the mechanical arm free path planning, then, for the end of the mechanical arm group free path collision detection of the mechanical arm body and assembly of the environment, and select the shortest working path optimization criteria as path planning target, finally generate the mechanical arm assembly process optimal path.

Therefore, the no-touch path between the mechanical arm end starting point and the target point can be planned according to the spatial obstacle identification and detection results. At the same time, in order to ensure that the assembly process is not collided with any object in the working area, need further collision of the mechanical arm ontology, to describe the mechanical analogy ontology geometric features, simplify each link to different cylinders and spheres, using three-dimensional space interior relationship to avoid obstacles, mechanical arm body collision detection envelope diagram is shown in Fig. 3.

First, a collision detection method based on the surrounding ball is proposed for spherical obstacles. By introducing the length and radius of each link of the mechanical arm, we determine whether the distance between the surrounding ball and the center of the ball in the link is greater than $r1 + r2$, and the safety margin can be added according to different operation requirements.

A collision detection algorithm is adopted by turning the AABB surround box for rectangular obstacle collision detection into an intersection problem between the spatial

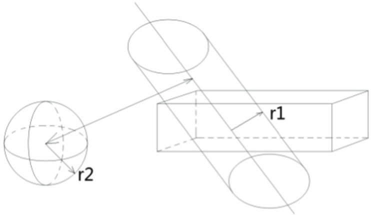

Fig. 3. The system composition diagram

linear segment and the cuboid edges. The minimum and maximum values of the projection of the AABB are (lx, ly, lz) and (ux, uy, uz), select the starting point (xi, yi, zi), and pass the entire line in one step length. If one point is in the l and u areas, the mechanical arm and the AABB enclosure box collide [9].

3.3 Product Grab

Based on the principle of force sealing, use the mechanical claw to achieve the product grasp and assembly release. Successful grasping surge should often meet the requirements of stability, balance and anti-interference. The balance refers to the force and moment on the captured target is 0; Stability refers to the object position or grip force error caused by external interference will return to normal state with the disappearance of the interference, That is, when in a non-equilibrium state, Compensation power can be generated to quickly restore the balance; Anti-interference resistance means that when the force closure or form-closure conditions are satisfied, Can resist interference in any direction.

The product grasping process is a soft contact grasping in the grasping contact model, and the contact force can be decomposed into the normal force, the tangential force and the contact normal torque.

The structural safety of terminal actuator equipment greatly depends greatly on the reasonable design of dry bearing structure, so it puts forward high requirements on the strength, stiffness, toughness and fatigue resistance of the main frame structure. In the design, through the 3D solid modeling, and then the mechanical simulation analysis, and the buckling stability and deformation amount are analyzed, according to the simulation results of the continuous structural optimization, Finally, a more optimized body bearing structure is obtained, as shown in Fig. 4.

The control part mainly realizes the communication with the main control end, motor control, micro force sensor state acquisition, etc. It intends to adopt the motion controller + servo driver + motor + force sensor. The motion controller operation control program is to receive and analyze the command and collect the master control end sensor in real-time state, and sends the command to the servo driver to control the motor operation.

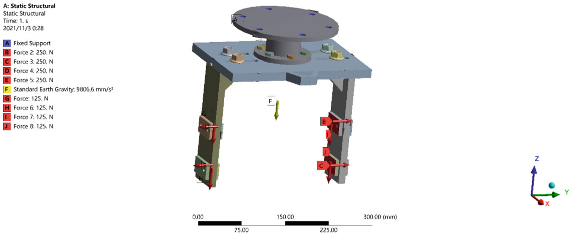

Fig. 4. Main frame structure

3.4 Flexible Assembly

The six-dimensional force sensor can measure 3D orthogonal forces (Fx, Fy, Fz) and 3D orthogonal moments (Mx, My, Mz) in any force system in space. Under static conditions, the force and torque data measured by the six-dimensional force sensor of the robot wrist are caused by three parts: 1) system error of the sensor itself; 2) load gravity; 3) external contact force affected by the load. In order to obtain the external contact force of the load, the influence of sensor system error and load gravity [10].

The components of the external forces on the three coordinate axes of the sensor are:

$$\begin{cases} F_{ex} = F_x - F_{x0} - G_x \\ F_{ey} = F_y - F_{y0} - G_y \\ F_{ez} = F_z - F_{z0} - G_z \end{cases} \tag{2}$$

The components of the external torque on the three coordinate axes of the sensor are:

$$\begin{cases} M_{ex} = M_x - M_{x0} - M_{gx} \\ M_{ey} = M_y - M_{y0} - M_{gy} \\ M_{ez} = M_z - M_{z0} - M_{gz} \end{cases} \tag{3}$$

Equation (2) and (3) are used to complete the compensation on the sensor zero point and the load gravity effect, and to get the external force and torque of the load.

4 Experimentation Validation

According to the above system establishment and technical application results, the whole system is tested to verify the function realization of the end actuator. The test system consists of the following parts: (1) end-actuator system; (2) mechanical arm system; (3) AGV system; and (4) integrated control system, as shown in Fig. 5.

4.1 Experimentation Items

The Experimentation items are as follows:

1. Test to capture and assemble the predetermined position by identifying the installation hole position;

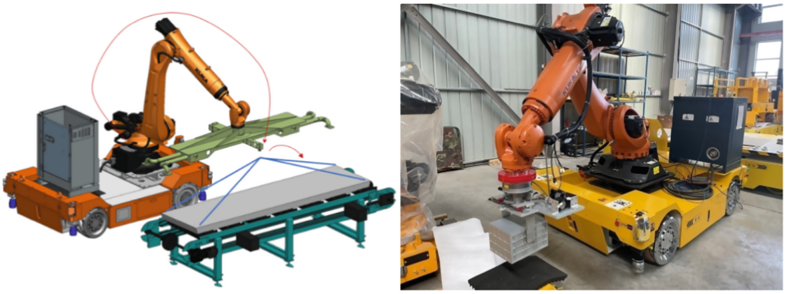

Fig. 5. Experimental diagram & Experimental process

2. Test to capture and assembly by identifying the text information of stand-alone equipment;
3. Test the visual system to extract the characteristic contour data of the test parts;
4. Test whether the assembly process can be adjusted for posture according to the preset obstacle parameters to avoid collision;
5. Test the deviation between the grip force and the theoretical value, test the hole deviation.

4.2 Experimentation Results

1. Successful hole location identification and precise positioning operation, as shown in Fig. 6.

Fig. 6. Hole matching effect

2. Successfully identify equipment contour and extract equipment information, as shown in Fig. 7.

Fig. 7. Character recognition effect

3. The robotic arm can guide the movement to the grasp position according to the identified features and the posture relationship of the visual system coordinate system;

As shown in Fig. 8, the six types of style characters designed can effectively identify the text information in the figure. In addition, the type 4 black and white characters have the best recognition effect.

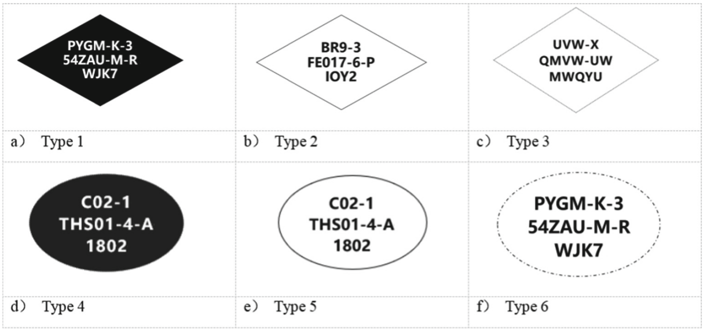

Fig. 8. The six types of style characters

4. The assembly process can achieve posture adjustment, and the assembly process without collision, as shown in Fig. 9.

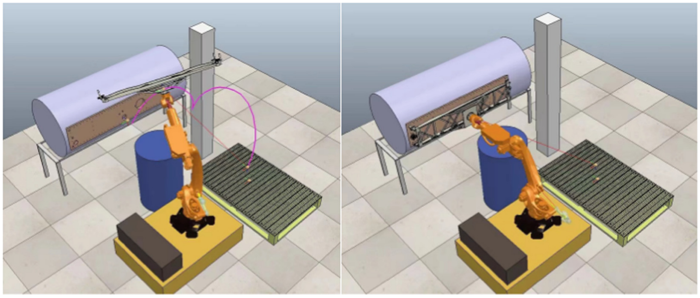

Fig. 9. Col-free assembly process

5. In no less than 10 tests, the grasp force deviation shall not exceed ± 0.5%, which meets the force requirements of the captured equipment, the maximum deviation of the hole is 1.8 mm, and the matching error can meet the smooth grasping operation of the assembly.

5 Conclusion

This paper discusses a terminal actuator system used for spacecraft assembly conditions. The system is well designed, manufactured, installed and tested to meet the accurate docking, grasping and collision-free assembly process of spacecraft products during remote operation. Grasp force deviation does not exceed ± 0.5%, the maximum deviation of the hole is less than 1.8mm. The system has been used in the assembly and production process of some spacecraft, providing a strong foundation for the subsequent automatic assembly technology of spacecraft products.

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