Flexible Assembly System with Stiffness Switching Joint

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Abstract

In this research, we aim to construct a flexible assembly system and realize precise assembly work by using a flexible-rigidity switchable joint for the wrist part of an industrial robot. One of the basic works in assembly work is Peg-in-Hole task. We install magnets in the joints and change the structure of the joints by changing the state of attraction and repulsion of the magnets. The joint has two states, which are low stiffness and high stiffness. The experimental data shows that switching stiffness improves the success rate.

Keywords: Peg in Hole, Precise assembly, Stiffness switching, Robot joint.

1. Introduction

For many years, the introduction of industrial robots has made progress in automation at production sites. Along with this, the production system is also shifting from line production to cell production, but in many cases, cell production relies on human labor. Especially in the assembly work performed by industrial robots, it is not easy to automate precision fitting, and even today, many assembly tasks rely on human labor. One of the basic works in assembly work is the fitting (Peg-in-Hole) work of the peg to the hole. In order to realize the mating work, it is necessary to suppress relative errors in the position, posture, and insertion direction between the peg and the hole within the clearance. Therefore, in automated assembly work, peripheral devices such as vision sensors, force sensors, and jigs are used to achieve high-precision positioning. In the case of preparing a jig for each part, in addition to the increase in time and money costs, it is not possible to respond flexibly to variable-variety variable-volume production. Amid the problems of labor shortages and rising labor costs due to population decline in Japan, realization of a flexible and rapid assembly system that can handle variable-variety variable-volume production is desired. We decided to achieve this goal by making a joint with variable stiffness. The joint has two states, which are low stiffness and high stiffness. The joint is equipped with magnets and springs, and the structure of the joint is changed by changing the state of attraction and repulsion of the magnets.

2. Related works

A hardware-based method that elastically supports workpieces and a software-based control method that uses data from sensors are being researched as methods [1],[3],[4] for realizing fitting work. The former is a passive alignment method, and the latter is an active alignment method. A hardware-based method is Remote Center Compliance (RCC) proposed by Whitney[1]. RCC is a function in which the center of elasticity is near the tip of the peg. To realize the function of RCC, the position of the elastic center must be changed according to the size of the workpiece. In addition, many elastic devices such as RCC are designed assuming mating work in which insertion is performed in the direction of gravity. Therefore, an elastic device that can handle various types of workpieces and arbitrary insertion directions is desired. Kim[2] proposed a hybrid variable stiffness actuator (HVSA), which is a variable stiffness unit design. The proposed HVSA is composed of a control module and a drive module. By controlling the gears in the control module, the position and stiffness of a joint can be controlled.

3. Fabrication of joints

3.1. *Purpose*

In fitting work, it is necessary to keep relative errors in the position, posture, and insertion direction between peg holes within the clearance. If an error exceeds the clearance, the peg and hole will come into contact and exert forces and moments on each other. If the error is large, the frictional force increases, and bite may occur. The purpose of making the wrist part of the compliant joint is to passively absorb this error. On the other hand, a weak point of flexible joints is that the posture of the hand is susceptible to external forces. The hand position is not reproducible with the same robot motion. In order to solve these problems, the joint used for the wrist of the robot to be manufactured can be switched between a low-rigidity state and a high-rigidity state with one joint. In this low-stiffness mode of the joint, as shown in Fig.1. The joint is given 6 degrees of freedom to achieve the mating and withdrawal motions of the peg.

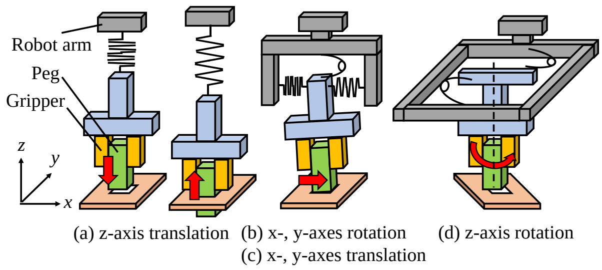


Fig.1 DOF of the compliance at the low stiffness mode

3.2. *Structure*

The developed joint is shown in Fig.2, and the structure of the joint is shown in Fig.3. It becomes possible to displace in the direction when a force or moment acts on the part. The degree of freedom of translational and rotational motion on the x and y axes can be obtained by forming the entire circumference of the two upper and lower shafts with silicone. When a force or moment acts in these directions, the silicone deforms, and the position and posture of the gripper change, making it possible to passively absorb the error between the peg and the hole during mating work. Above the plate connected to the peg is a guide connected to a spring. The space between the plate and the guide is covered with silicone, and when it receives a rotational moment around the z-axis, the silicone deforms, and the gripper rotates. In addition, the N-pole magnet attached to the rotating part around the z-axis faces the N-pole magnet of the flat plate, and the flat plate receives the repulsive force of the magnet. At this time, the plate stops at the position where the magnetic force, the elastic force, and the gravitational force of the gripper and the grasped object are balanced. When an external force in the z-axis direction is applied to the gripper, the joint is displaced in the direction in which the force acts. In the high-rigidity mode, the N-pole magnet of the rotating part faces the S-pole magnet of the flat plate, and the flat plate is attracted to the rotating part by receiving the attraction force of the magnet. Conical pins and holes on the bottom of the flat plate mesh with each other to restrict all movements and suppress the effects of external forces. Switching between both stiffness modes is performed using a servomotor (DynamixelXM430-W210, Robotis).

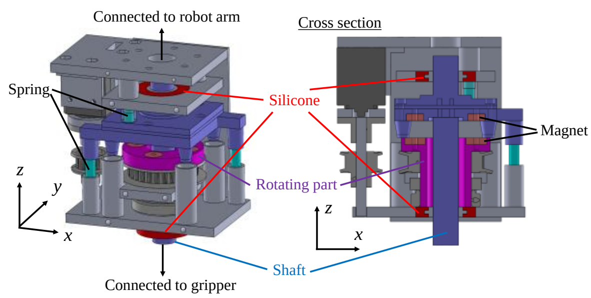


Fig.2 Developed stiffness switching joint

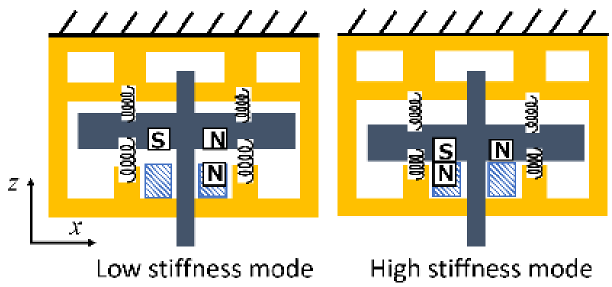


Fig.3 Schematic of both stiffness modes

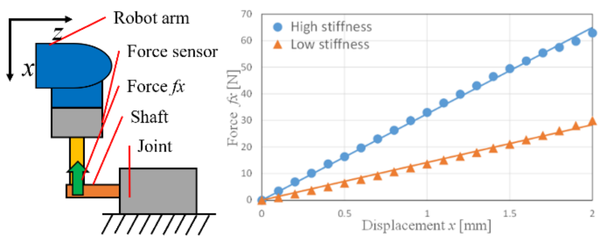


Fig.4 Schematic and result of the stiffness measurement

4. Evaluation experiment

4.1. *Stiffness measurement*

As shown in Fig.4, we measured the stiffness in the x-axis direction in both stiffness modes. Fig.4 shows the measurement results of the force when pushing the joint axis using a robot arm connected to a 6-axis force sensor. The magnitude of the force required for displacement in the x-axis direction in the high-rigidity mode is about 2.3 times that in the low-rigidity mode.

4.2. *Fitting work*

As shown in Fig.5, fitting work was performed using the manufactured joint. The joint is connected to the servo motor and the peg (Φ16.88) in that order, and it is fitted into the hole (Φ17.02) on the board. [5] showed that the success rate is improved by utilizing the rotation of the peg in the fitting work of a robot with a flexible wrist. The motion was 10 N, and the peg was pressed against the hole on the plate, rotated clockwise for 3 seconds, and inserted 50 mm when the fitting was successful. In the low-stiffness mode, the joint has an axial stiffness that displaces about 2mm at 10N. Experiments were performed in both stiffness modes by changing the position of the peg with respect to the hole. Fig.6 shows the position of the peg when the peg insertion was successful and failed. The origin of the peg position is the position where the peg can be inserted into the hole without interference. The frictional force acting in the direction of insertion of the peg is examined. Fig.7 shows the relationship between the distance from the origin of the peg and the magnitude of the friction force in both stiffness modes. The frictional force shown is the maximum value at 50mm insertion. In the high-rigidity mode, the greater the positional error, the greater the frictional force generated, requiring a large insertion force. On the other hand, in the low-rigidity mode, the friction force is suppressed to 1N or less at any positional error, which is lower than in the high-rigidity mode. This is because the joint compliance reduced the drag force between the peg and the hole. Therefore, in the low-rigidity mode, the required insertion force is reduced, and it is possible to cope with cases where the friction coefficient between peg holes is high.

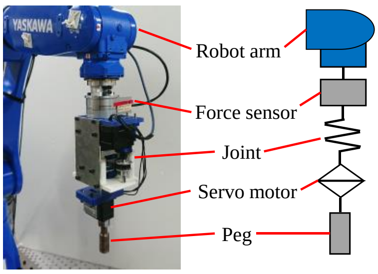
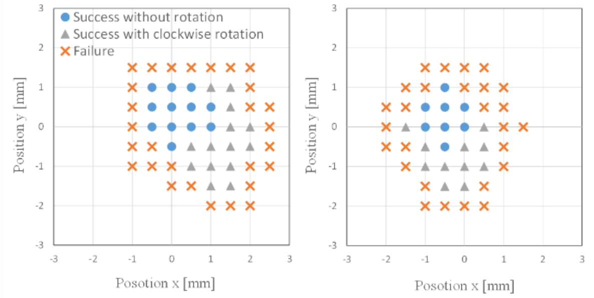


Fig.5 Schematic of the Peg-in-Hole experiment



(a) High stiffness mode (b) Low stiffness mode

Fig.6 Success area of the Peg-in-Hole

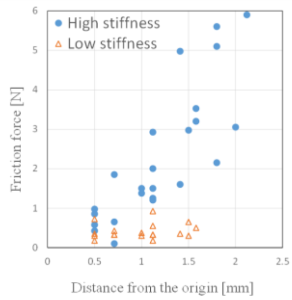
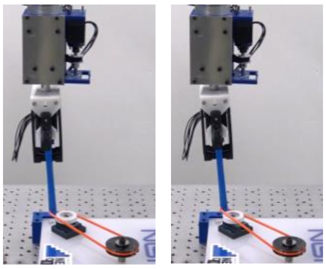


Fig.7 Friction force of the Peg-in-Hole

4.3. *Belt assembly work*

We assemble the belt with the proposed joint. A parallel gripper is connected to the joint, and a belt with a diameter of 4 mm and a circumference of 400 mm is assembled on pulleys with a center distance of 135 mm. Fig.8 shows the moment when the belt is put on the second pulley in both stiffness modes. In the low-rigidity mode, the center position of the joint and the gripper fingertip position deviate greatly due to the displacement of the joint axis due to the belt tension. Therefore, in order to change the position and posture of the gripper fingertip, it is necessary to move the robot considering the deformation of the joints. In the high-rigidity mode, it is possible to work while suppressing the effects of joint deformation due to tension.



(a) High stiffness mode (b) Low stiffness mode

Fig.8 Belt assembly experiment

5. Conclusion

In this research, we developed a flexible/rigid switchable joint for the wrist of a robot to realize precise assembly work. The effectiveness was verified with the actual assembly work.

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Authors Introduction

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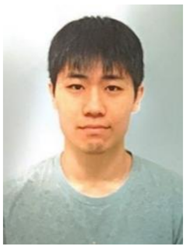

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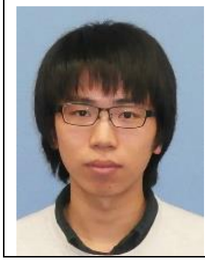

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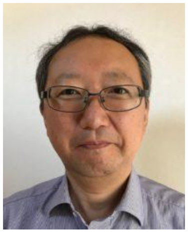

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