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Design of a 5-DOF flexure based passive gripper

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Abstract

A 5-DOF flexure based passive gripper is designed for pick-and-place and insertion task. The proposed design eliminates the use of expensive actuators and sensors to achieve proper alignment. The gripper consists of gripper base and flexure stage. The gripper base, which is responsible for picking the object, is based on sheet flexures which provide the required gripping force. A cost-effective and easy to manufacture 5-DOF (two translational and three rotational degrees of freedom) flexure stage, with higher stiffness in direction perpendicular to the plane of the object as compared to other directions, is designed and studied using kinematic design principles. An FEM model was developed to calculate stresses and the range of motions. A candidate gripper is designed and realized using 3-D prototyping method and tested for performance. The gripper is capable of picking 200 gm rectangular object and handling 2 mm linear and 5 degree rotational misalignments. The gripper can be customized for various geometric shapes, sizes and alignment requirements depending on the application.

Keywords – gripper, flexure, degrees of freedom, misalignment, pick, insertion

1. Introduction

Grippers are used for various pick-and-place and insertion tasks. Typically, these grippers are actuated electrically, pneumatically or hydraulically, which may require expensive or bulky components. For insertion operations, the misalignment may lead to jamming and wedging of parts. One way to overcome this problem is to use sensors to detect the error in position and orientation of gripper and subsequently correct for the misalignment. This method is expensive and requires a lot of computational power [1]. Another solution is a passive device using shear pad based remote centre compliance to reduce misalignments [2]. These devices eliminate the use of any sensor, but they are expensive and bulky. A comparatively compact and lighter passive device is proposed in [3], which provide a five degree of freedom (DOF) stage based on wire flexure.

In this paper, a passive flexure based gripper is proposed, which is easy to manufacture and capable of handling limited misalignments. Finite element method (FEM) is used to validate the design. A gripper (Figure 1a) was realised via 3-D printing using ABS material for picking a cuboid of dimension 20 mm × 20 mm × 40 mm and inserting into a hole of same dimensions with wall thickness 2mm.

2. Design of gripper

The gripper consists of gripper base – responsible for picking and insertion, and flexure stage – responsible for proper alignment. The whole process of picking and insertion is divided in three steps – picking, alignment and release.

2.1. Picking

As shown in Figure 1a and 1b, gripper base consists of four identical cantilever beams, each with a friction pad at its end, with small overhang. When the gripper is pushed towards the object, the sheet flexure deflects making way for the object to get in place. Due to this deflection, cantilever beams undergo buckling and apply reaction force to the object. The reaction force is calculated by post buckling analysis [4]. The analytical results were verified using FEM model. The friction pad attached

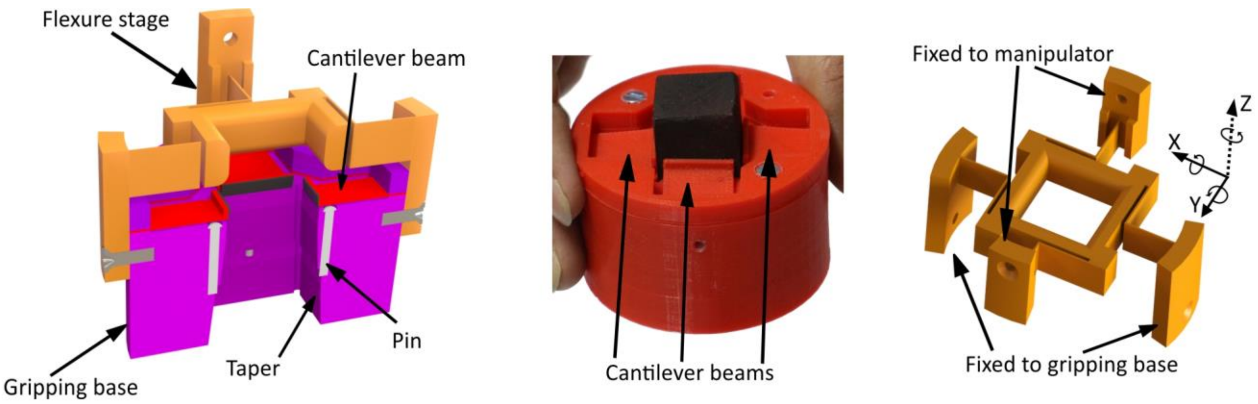

Figure 1. a) Section view of complete gripper (left); **b)** Deformation in cantilever beams, attached to gripper base, while holding a square block (centre); **c)** Flexure stage with five degrees of freedom (right).

Figure 2. Manufactured gripper tested for translational misalignment along Y-axis (left), rotational misalignment along Y-axis (centre) and rotational misalignment along Z-axis (right).

at the end of the cantilever beam applies frictional force on the object, which prevents the object from falling. The force applied by the cantilever beam depends on the dimensions and mechanical properties of the cantilever and the amount of the overhang. The set of four 16 mm long, 10 mm wide and 0.5 mm thick sheets with 0.2 mm overhang, was tested for picking an object of 200 gm.

2.2. Alignment

During an insertion process, inaccuracies in the moving system lead to position and orientation errors. For successful insertion, the gripper should have higher stiffness in the translational direction perpendicular to the plane of the object as compared to other two translational and three rotational directions. Therefore, a 5-DOF stage with decoupled rotation and translation is required.

A wire flexure is stiff along the axis of flexure and has five DOF. Mounting the gripper using it should serve the purpose, however it is prone to buckling and eccentric loading due to misalignment. A compliant stage using four folded sheet flexures is therefore designed using kinematic design principles [5].

Connecting two folded sheet flexures in parallel, such that one sheet of both the flexures lies in the same plane and fold line of both the flexures is parallel to each other, results in four DOF constraining one translation motion, parallel to fold line, and one rotational motion, perpendicular to the common plane of two sheets. Two sets of such flexure, one connected to gripper base and other to manipulator, connected in series and perpendicular to each other result in a five DOF flexure stage, as shown in Figure 1c. As soon as the gripper comes in contact with the walls of the hole, appropriate element of flexure stage will deform in order to reduce any misalignment. Maximum allowable misalignment (rotational as well as translational) depends on the dimensions of each element of the flexure as well as on the material properties of the element. Therefore, a suitable flexure stage can be constructed by varying these properties.

One such flexure stage was fabricated using 3-D printing techniques with ABS plastic material. Each sheet is 14 mm long, 10 mm high and 0.5 mm thick. An FEM model was developed and analysed for the required performance. Experiments were performed on the fabricated set-up. The flexure stage is capable of handling 2 mm linear and 5 degree rotational misalignments. Figure 2 demonstrates the deformations in flexure elements in order to overcome three of the five possible misalignments. Figure 3 compares the deformation and stresses in the set-up and the FEM model for a misalignment in X-axis.

Beside the flexure, the base is also modified for handling the misalignments. As shown in Figure 1a, a taper is introduced in the inner walls of the base such that the object and the walls of the hole are guided inside the base despite any misalignments as base approaches them.

2.3. Release

After picking, the next task is to insert and release the object into the hole. This is achieved by placing four pins, just below each cantilever beam, inside the base as shown in Figure 1a. As the base is moved towards the hole, the pins are pushed by the walls of the hole. Due to this motion, cantilever beams are deflected sufficiently such that they lose contact with the object and the object is released.

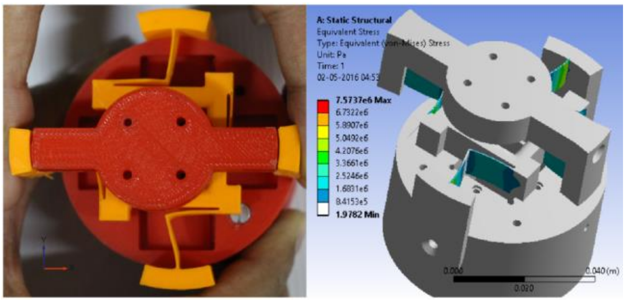

Figure 3. a) Deformation on the flexure elements for positional misalignment along X-axis, **b)** Stresses on the flexure elements using FEM model.

3. Conclusion

A 5-DOF flexure based passive gripper was designed and fabricated with ABS plastic material of size 62 mm high and 60 mm wide. The gripper was tested for picking an object of size 20 mm × 20 mm × 40 mm and inserting it in a hole with wall thickness of 2 mm. The gripper is capable of handling 2 mm linear and 5 degree rotational misalignments. The gripper was designed for cuboidal objects but it can be adapted for different geometric shapes by changing the number and the overhang of the cantilever beams. The design is easy to manufacture and maintenance free. Its compact size, lightweight and capability of handling misalignments makes it a perfect replacement for traditional grippers.

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