Research on robotic assembly of gear motors (Stator recognition using keypoint matching and stator insertion using contact position estimation)

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Abstract

This paper describes a robotic assembly system for gear motors. Currently, automation through the introduction of robots is being actively implemented in various fields. However, assembly tasks, which require dexterous skills, are still often performed manually. Humans use information such as vision and hand sensation to accomplish these tasks. Therefore, research is being conducted to develop assembly robots using cameras and force sensors. In this paper, two main methods, key point matching and contact position estimation, are used to realize the gear motor assembly work, which is the insertion of the stator into the reducer. Keypoint matching is used to recognize the position and orientation of the part using a camera. Contact position estimation is used to detect contact between parts in the insertion process using a force sensor to prevent failure of the insertion operation. An experimental system using these methods is developed to achieve automatic stator insertion.

Keywords: Robotic assembly, Keypoint matching, Contact point estimation, Gear motors, Image sensor, 6-axis force sensor

1. Introduction

A gearmotor (Fig. 1) is a motor packaged with a reduction gear connected to the rotating shaft of a DC or AC motor and is widely used in cranes and transport equipment. Currently, gearmotors are assembled manually, which requires high level skills, such as the sense of dexterity and visual information of skilled workers. Tanaka et al. [1] discussed a grasping system of a small nut, based on force or current measurements. Satoh et al. [2] discussed precision assembly tasks of a polygon mirror, based on forces and moments and the orientation of the part.

This paper describes a method of automatic stator insertion in the assembly sequence of gearmotors, on the basis of which the rotor is assembled in the reduction gear unit. Section 2 describes an overview of the automatic assembly equipment as a hardware configuration. Section 3 describes key point matching for stator angle recognition as a vision system and contact position estimation for preventing failures in insertion operations. Section 4 then examines the effectiveness of the proposed automated assembly system using the methods in Section 3.

Fig. 1 Gearmotor

2. Setup of the experiment system

In this section, we describe our experiment system for this study. An articulated robot arm Denso VS-050 is used for assembling parts. A 6-axis force sensor Leptrino PFS055YA251, an RGB-D camera Intel RealSense D435, a 2-finger robot hand Robotiq 2F-140 are mounted on the end of the robot arm (Fig. 2). A reducer and motor manufactured by Tsubakimoto Chain Co. is used as the assembly target, and experiments is conducted in the assembly environment shown in Fig. 3. The reduction gear is set on a fixture created by a 3D printer. In this environment, the stator is grasped and assembled into the reducer.

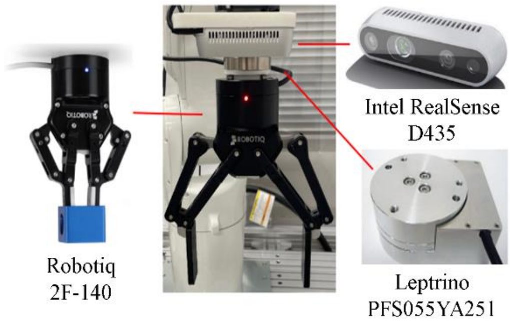


Fig. 2 Handling System

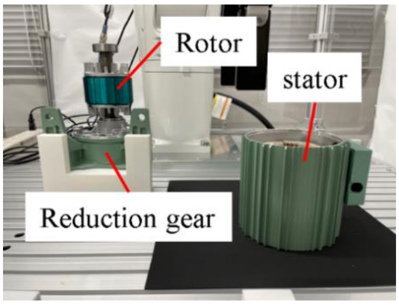


Fig. 3 Assembly Environment

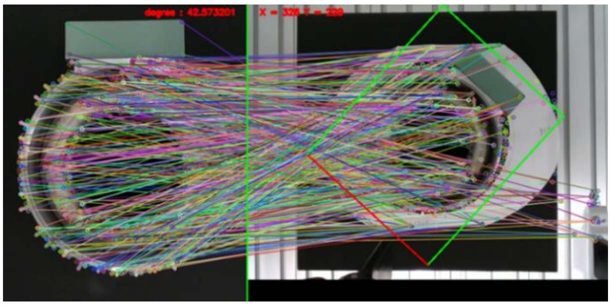
3. Assembling method

3.1. *Keypoint matching*

Keypoint matching first extracts keypoints from each of the template and target images that are robust to translation, scaling, rotation, and brightness changes. See Ref. [3] for details. This study uses Hamming distance to compute similarity. If both character strings are x and y, the Hamming distance $\mathrm{Ham}(x,y)$ can be defined by the following Eq. (1).

$$\mathrm{Ham}(x,y) \coloneqq \sum_{i=1}^{m} \begin{cases} 1 & (x[i] \neq y[i]) \\ 0 & (x[i] = y[i]) \end{cases} \tag{1}$$

Next, the top k keypoints with the highest similarity among the feature points extracted from each of the template and target are matched (Fig. 4). This is called k-NN matching. The affine transformation matrix (2 × 3) is estimated by RANSAC from a set of keypoints extracted from both the template and target images. The angle is then calculated from a total of three points: the center coordinates of the bounding rectangle of the target image and the upper left vertex coordinates before and after affine reconstruction (Fig. 5). The purpose of using this method is because the stator must be inserted at an angle that matches the threaded holes in the reducer and stator.



(a) Template Image (b) Target Image
Fig. 4 Keypoint Matching

(a) Template Image (b) Target Image
Fig. 5 Angle Detection Image

3.2. *Estimation of the contact point*

Since stator insertion is not always smooth, the optimal insertion position must be detected. For this purpose, the optimal insertion position is detected by repeating the corrective action of moving in the direction to avoid from the contact position using contact position estimation. Force and moment $(\boldsymbol{f}_i, \boldsymbol{m}_i)$, $(i = 1,2,\cdots,k)$ are measured from the 6-axis force sensor. In order to eliminate the offset of the force sensor, the deviation force $(\bar{\boldsymbol{f}}_i, \bar{\boldsymbol{m}}_i)$, $(i = 1,2,\cdots,k)$ from the average are utilized. Let $\boldsymbol{p}_c$ be the contact point position, we have $\bar{\boldsymbol{m}}_i = \boldsymbol{p}_c \times \bar{\boldsymbol{f}}_i$ in pure and ideal case. Considering that the measurement force and moment is contaminated with noise, the following evaluation function $J(\boldsymbol{p}_c)$ is defined by Eq. (2).

$$J(\boldsymbol{p}_c) \coloneqq \frac{1}{k}\sum_{i=1}^{k} \left\| \bar{\boldsymbol{m}}_i - \boldsymbol{p}_c \times \bar{\boldsymbol{f}}_i \right\|^2 \tag{2}$$

Minimizing the function, the position $\boldsymbol{p}_c$ is estimated by the following formula:

$$\hat{\boldsymbol{p}}_c = \left(\frac{1}{k}\sum_{i=1}^{k}[\bar{\boldsymbol{f}}_i \times]^2\right)\left(\frac{1}{k}\sum_{i=1}^{k}\bar{\boldsymbol{m}}_i \times \bar{\boldsymbol{f}}_i\right) \quad (3)$$

The function $J(\boldsymbol{p}_c)$ has the minimum value $s_k := J(\hat{\boldsymbol{p}}_c)$. Uncertainty region of the estimate $\hat{\boldsymbol{p}}_c$ is defined as the region satisfying the following condition.

$$J(\boldsymbol{p}_c) \leq 2s_k \quad (4)$$

The region is given by an ellipsoid centered at the estimate. See Ref. [4] for the derivation of the region.

4. Experiments

4.1. *Procedure of experiments*

We perform the following steps.

Step 1: Recognize the stator by Hough transform.
Step 2: Recognize the angle of the stator by keypoint matching.
Step 3: The robot hand grasps the stator and moves it to just above the reducer.
Step 4: Perform the insertion operation. If contact is made with the rotor, then corrective action is taken until the proper insertion position is reached.
Step 5: Once the proper position has been detected, the insertion should be completed.

The details of **Steps 4** and **5** are shown in Fig. 6.

Success condition: After inserting the stator, screws can go through both screw holes of stator and reducer manually.

Number of trials: 10 trials for each of the 8 conditions (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) where the stator contacts the rotor as seen in the robot coordinates, 80 trials in total. The robot coordinates and angular orientation are shown in Fig. 7. In the initial condition of the experiments, the stator is shifted in advance about 2 mm from the nominal aligned position.

4.2. *Results of the experiments*

Experimental success rate was 100 % in all conditions. Table 1 shows the average time when the condition is 45°. Fig. 8 and Fig. 9 show the estimates of the contact position and its uncertainties of XY components are also shown in the case of 90° Fig. 10 shows force measurement of z component. The sampling time of the force sensor is 18.6 msec and the last 20 data ($k = 20$) are used in Eq. (3). From Fig. 10, the contact repeatedly appears in the samples from 226 to 316. If the uncertainty is small, the estimate $\hat{\boldsymbol{p}}_c$ is valid. Note that Figures 8, 9 and 10 focus on the valid range of estimation.

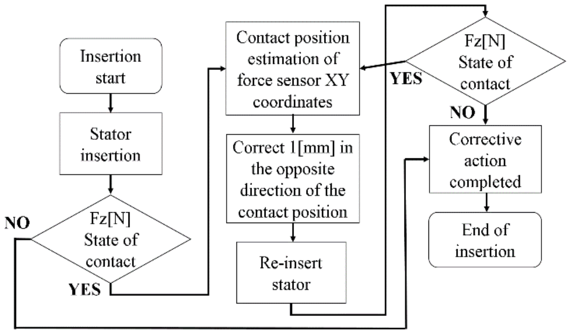


Fig. 6 Flowchart of the insertion process

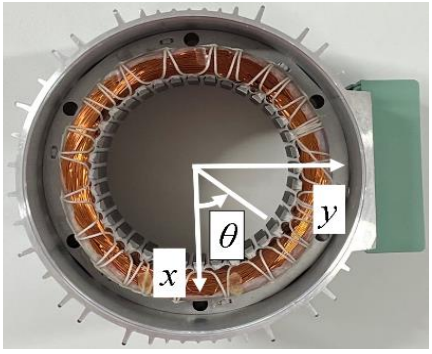


Fig. 7 Image of contact position by angle

Table 1 Average time in case of 45°

Test time	171932.8 msec
Adjustment operation time	69422.8 msec

5. Conclusions

In this paper, the robotic assembly of the gearmotor was discussed. The process that the stator was recognized, grasped and inserted into the reducer was performed using two main methods (keypoint matching and contact position estimation). The validity of these method was verified by experimentation.

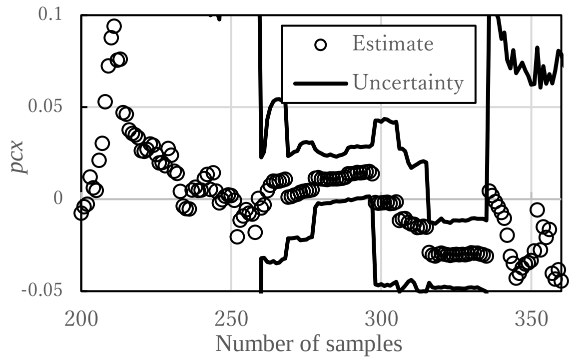


Fig. 8 Estimates of p_{cx} and its uncertainty

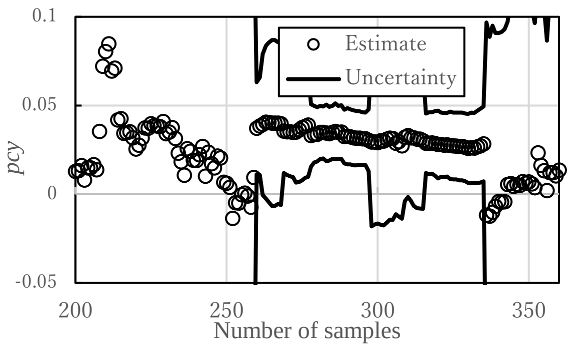


Fig. 9 Estimates of p_{cy} and its uncertainty

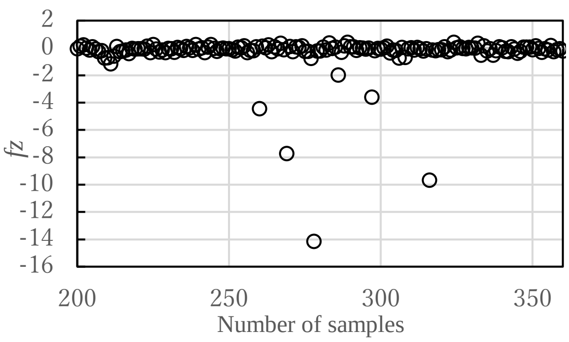


Fig. 10 Measurement force f_z

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