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Development of Assembly Robot System for Flexible Belt-Shaped Subject

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We develop an assembly robot system for assembling the flexible belt-shaped subject. An image processing method is developed to recognize the belt-shaped subject. This method is able to determine the grasping point and grasping angle for piking up a subject by a multiple hands unit. CAD information is used to determine the grasping point. The multiple hands unit is developed, which is able to grasp all grasping points of a subject at a time. In addition, the image processing method is used to judge whether a subject is fastened accurately at right position or not during the assembly.

1. INTRODUCTION

Various kinds of flexible belt-shaped subjects are used in the assembly processes. Although the introduction of robots has promoted automation of many assembly processes, assembly of soft subject has not been automated yet. [1]

It is the one of most difficult problems to be solved for advancement of the automation. Therefore, we tried to develop an assembly robot system, for the purpose of assembling the flexible belt-shaped subject. Firstly, on the basis of the CAD figure, grasping positions on a subject are decided so that the shape of the subject could be kelp remain unchanged during assembly work. Next, a unit of multiple hands is designed, which is able to grasp plural grasping positions at a time. An image processing method is developed to recognize the shape of subject before grasping, and determine the grasping positions on a subject comparing with the data obtained by CAD figure. [2] [3] An inspection method is also developed for judging whether each subject has been assembled accurately at a right position or not. Finally, an assembly robot system is developed by using the above mentioned methods and the multiple hands unit.

2. PROPOSED METHOD

2.1 Assumptions

Following conditions are assumed.

(i) Assembly is possible even if a subjects is curved or distorted in a vertical plane.

(ii) The stiffness coefficient and the weight per length of a subject are uniform.

(iii) Flexible subject is supplied one by one to a flat working table without being twisted or overlapped. [4] The subject is picked up and assembled to a rigid object fixed on another working table or JIG.

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2.2 Symbols

Some key symbols are shown as below.

$D_\ell(DI_\ell, DJ_\ell)$: Coordinate of ℓ-th pixel on the contour line of belt-shaped subject. (ℓ=1,2, ... ,N)

N : Number of pixel (ℓ) on contour line of an subject.

AN_ℓ : Opening angle (Fig.3) of pixel (ℓ).

2.3 Determination of Grasping Points

The grasping position is determined form the CAD figure of a subject so that the deformation of subject should be minimalized. Additionally, the number of grasping position is also paid attention to be minimized as possible as they could.

2.3.1 Modeling of distortion of the subject

Fig.1 shows a model of distortion. There is two inflection points where the flexure is beginning and ended. A symbol DE_j represents the distance from j-th point on the subject to a virtual line connecting start point and end one of the flexure. Then, the evaluation value MD of the flexure is defined by eq. (1).[5]

$$MD = \sum_{j=J}^{N} DS_j \cdot \max\{DS_j^2\} \qquad (1)$$

The amount of flexure increases by growing of the evaluation value MD.

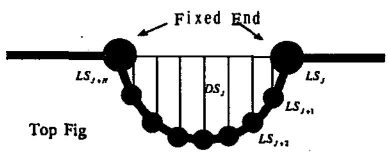

Fig.1 An evaluation model of the flexure

2.3.2 Determination of grasping points

Grasping point is determined by following process considering the flexure.

(i) Grasp from the upper side at the convex part. (Prevention of flexure)

(ii) Grasp the inflection point in horizontal plane. (Prevention of twist and spacing)

(iii) The above mentioned position is determined from the evaluation value MD of all flexures under the assumption that a subject would be held at a time.

(1) MD < LMD

The amount of twist and spacing between the consecutive grasping points are examined to evaluate whether one or the other grasping point could be eliminated. If MD is smaller than a pre-examined constant value LMD, then such point is eliminated from candidates to minimize the number of the multiple hands unit. The actual grasping position is chosen from candidates considering following conditions.

(2) LMD ≦ MD ≦ HMD

If above condition is satisfied, this section could be assembled. So two grasping points are determined.

(3) HMD < MD

If MD exceeds a constant value HMD, the point which becomes the maximum of DS_j is chosen additionally as a grasping point. Here, LMD and HMD are given by measuring real belt-shaped subject.

2.4 Image Processing Method for the Recognition of the Belt-Shaped Subject

2.4.1 Composition of the assembly robot system

(a) This system in Fig.2 is composed of the image processor, robot with 6 degrees of freedom, computer, three

CCD cameras and switching unit.

(b) The multiple hands unit hold up aligned subject, and move it to another working table-2 for assembling the subject.

(c) Camera C1 takes an image at upper side from the working table-1 to recognize overall picture of a subject. Camera C2 is set at upper side from the other working table-2 and used for the inspection. Camera C3 is set at horizontal side. They are used to determine the grasping position precisely by the multiple hands unit to grasp a subject.

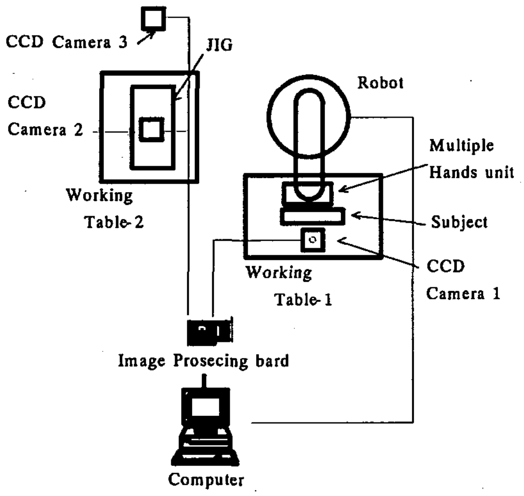

Fig.2 Assembly robot system

2.4.2 Determination of a reference point

Corners of flexible belt-shaped subject usually could keep the original shape, because the stiffness coefficient is bigger than that of other flat segment. So corners of subject are chosen as reference point which will be matched with the CAD figure. Therefore, a method is required for recognizing corners on the contour line. The corner could be recognized by measuring the opening angle.

(1) Estimation of opening angle at a corner

The opening angle is calculated by CAD figure and contour line in the input image. The image processing is carried out to make out the contour line in the input image and CAD figure. Next, the opening angle AN_ℓ at pixel ℓ is defined by eq. (2).

$$AN_\ell = \left| \arctan\left(\frac{DJ_{\ell-NA} - DJ_\ell}{DI_{\ell-NA} - DI_\ell}\right) - \arctan\left(\frac{DJ_{\ell+NA} - DJ_\ell}{DI_{\ell+NA} - DI_\ell}\right) \right| \times \frac{180}{\pi} \qquad (2)$$

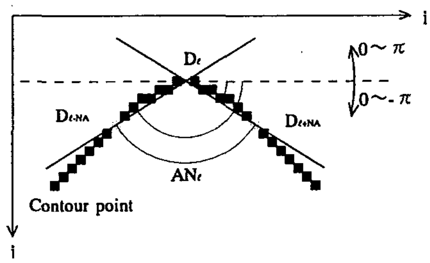

Fig.3 Calculation of opening angle

Where, two points (position $D_{\ell-SA}$, $D_{\ell+SA}$) are set at intervals away NA pixels from the point D_ℓ on the contour line. NA is given experimentally.

(2) The identification of corner

The corner is identified based on the opening angle AN_ℓ. However, each subject has several corners. So, the opening angle of every points on the contour line are shown in a figure in Fig.4. The vertical axis represents the opening angle AN_ℓ and horizontal axis represents ℓ-th pixel on the contour line. The minimum value of opening angle AN_ℓ is searched in this graph. The pixel with the minimum value AN_ℓ is chosen and set as corner C_k. Corner C_k satisfies the following equations. Where, the constant values AS and NC are given by pre-examination.

$$AN_\ell \geq AS \quad (MS_k \leq \ell \leq ME_k,\ 0 \leq AS \leq \pi) \qquad (3)$$

$$|ME_k - MS_k| \geq NC \qquad (4)$$

$$C_k = \min_{MS_k \leq \ell \leq ME_k} \{AN_\ell\} \qquad (5)$$

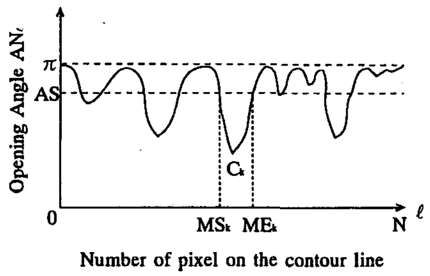

Fig.4 Opening angle of pixel on the contour line

2.4.3 Determination of grasping points and grasping angle

Grasping point on a subject is not always parallel to the horizontal line (i-axis). It is often inclined. Therefore, the direction of every robot hands should be adjusted so that they can grasp a subject accurately. Without this adjustment any robot hand could not hold the grasping point accurately. The angle of inclination HA_k at grasping point H_k is given by eq. (6). The angle HA_k is given as the mean value around the grasping point. Where, the symbol a and S are constant values given by experiments.

$$HA_k = \frac{\sum_{m=k-a}^{k+a} \phi_m}{2a+1} = \frac{\sum_{m=k-a}^{k+a} \left(\arctan \frac{DJ_{m-S} - DJ_{m+S}}{DI_{m-S} - DI_{m+S}} \right)}{2a+1} \qquad (6)$$

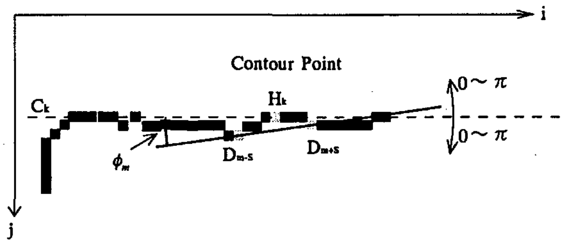

Fig.5 The grasping angle HA_k of the grasping point H_k

2.5 Grasping Procedure by Multiple Hands Unit

As the accurate positioning is required to assembly belt-shaped subject assured by following procedure.

2.5.1 Picking up by robot hands

Only two consecutive grasping points are held at first. Then the subject is lifted up so that other segments of the subject are sagged downward by their own weight. After that, the bottom face of the multiple hands unit is turned until it becomes parallel to the vertical plane.

2.5.2 Adjustment of posture of subject

The angles at both side at the grasping position (H_k) are calculated and represented by symbols $DL\theta_k$ and $DR\theta_k$. Where, angle $DR\theta_k$ is made by horizontal axis and the right side segment of the subject sagged downward. The ideal angles at the same point are calculated by using the CAD figure, and they are represented by symbols $BL\theta_k$ and $BR\theta_k$. Considering the difference between $DL\theta_k$ and $DR\theta_k$, the unit of multiple hands unit is rotated angle θ_k around its tool axis. The rotational angle is given by eq. (7) . The posture of subject could approach to vertical by this procedure. After the execution of above mentioned procedure, all hands could be closed.

$$\theta_k = \frac{(BL\theta_k - DL\theta_k) + (BR\theta_k - DR\theta_k)}{2} \qquad (7)$$

2.5.3 Recognition of other grasping positions

After subject is grasped with the multiple hands unit completely, it is positioned to the object by the following procedure.

① An image is taken from the bottom face of multiple hands unit. The contour line of subject is calculated by image processing by using outlining.
② The corners of subject are recognized.
③ The reference points are searched from the corners.
④ Grasping positions hold by multiple hands unit are calculated.
⑤ The number of pixel on contour line is calculated from the reference point to every grasping points.
⑥ The contour line of the rigid subject on a JIG is obtained by using outlining.
⑦ On the basis of ⑤ and ⑥, the positions for putting on the subject are precisely determined.
⑧ The subject is positioned actually. Where, the segments changing in vertical plane are positioned in advance.

2.5.4 Assembly by multiple hands unit

In order to assemble the subject, multiple hands unit should do the motion of grasp and insert at the same time. Each gripper of multiple hands unit has the following function. While holding the segment by gripping fingers, pushing lever goes down in order to insert the subject.(Fig.6) It is positioned to assemble the subject by these function, after multiple hands unit move on the JIG.

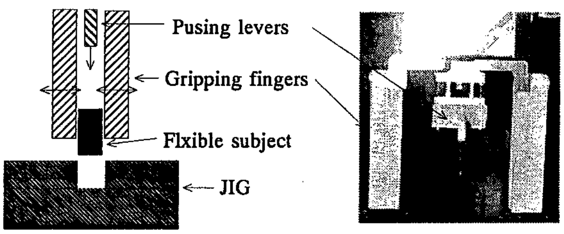

Fig.6 Function of grippers

2.6 Inspection

An image of subject is taken from its upwards by the camera, after the assembly of a belt-shaped subject. Then, the contour line of the subject is detected by the contour-tracing method. On the other hand, a virtual border line is drew around the periphery of the rigid object fixed on JIG. If the belt-shaped subject has been assembled accurately, its contour line never protrude the virtual border. If any portion of subject protrudes the virtual contour line, then that portion is faulty segment. Therefore, eq. (8) is defined in order to evaluate the accuracy of assembly.

$$J = \frac{M}{N} \times 100 \qquad (8)$$

Where, N is the length of virtual contour line and M is the length of segments protruding from the virtual contour line.

3. APPLICATION EXAMPLE

A assembly robot system is shown in Fig.7. This system is composed of one industrial robot with 6.D.O.F.[6] The assembly subject is also shown in Fig.7. As a result, the averaged operation time for one subject was about 120 sec, and success rate was about 60 %. Main factor causing failure is that each gripper grasped wrong position. For the sake of flexibility of the subject, the grasping positions are moved slightly comparing planned positions when the subject suspended. Therefor, some grippers grasped the slightly wrong positions. In order to minimize the error of grasping position, preliminary numerical analysis of the object is required from the viewing point of deflection.

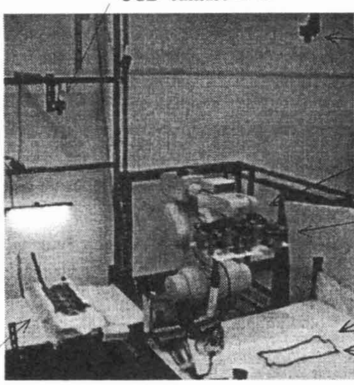

Fig.7 Assembly robot system

4. CONCLUSION

In this research we developed a robot system which could assemble the flexible belt-shaped subject.

Firstly, grasping positions on subject are determined to keep the shape of subject. Secondly, a multiple hands unit which can hold all grasping positions are developed to assemble subject accurately and to judge that it has been assembled accurately. Finally, an assembly robot system is constructed by using the proposed method and the multiple hands unit.

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