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学位授与の題目	Research on Clothes Manipulation by Robot （ロボットによる衣類のマニピュレーションに関する研究）
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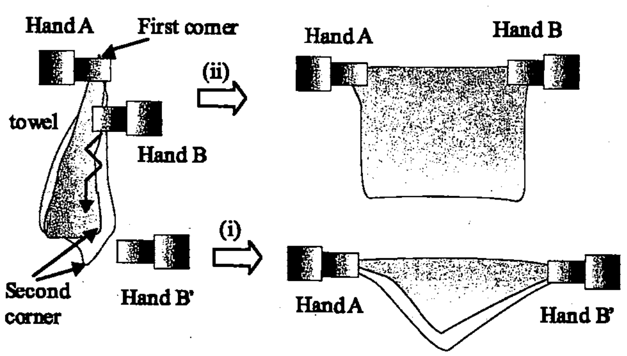
Abstract - Edge tracing is important in manipulating deformable objects to reveal their original shape. This research proposes a unique method for towel spreading using two robot arms with sensors-equipped grippers and a CCD camera. The method proposed and used is by using simple motion stereo method for grasping the first corner and then using an edge tracing manipulation method to find and grasp the second corner. Tracing in this paper context involves tracing the towel's edge. Robot arm movement is based on feedback from sensors and from images from the CCD camera. Our proposed tracing manipulation ensures that both corners grasped by robot are adjacent and not across, enabling the towel to be successfully spread. Two different new grippers are also designed to improve the tracing reliability. One is a gripper with roller mechanism at the fingertips that rotates only on its axis. This gripper has allowed more flexibility towards tracing manipulation by reducing the friction between the gripper and the fabric without having to apply too little force. The latter gripper is an inchworm type gripper. Having two pair of grippers instead of one, one of the gripper will always be holding the fabric while the other one traces the edge. Different tracing manipulation algorithms are proposed for each type of gripper and all algorithms are proven to be successful. Experimental results from spreading rectangular towels with different thickness, stiffness, smoothness, and color using our towel spreading method also demonstrated that our proposal is robust.
Keyword: Edge tracing, deformable object, robot gripper, spreading of clothes, home service robot

1. Introduction

One feature required from home service robots is the ability to manipulate deformable objects because of the large number of clothes, ropes, tubes, papers, etc., found in the home require dexterous handling. The presence of these objects means that home service robots need to be dexterous in object handling. In handling clothes, for example, the robot must first recognize the shape of clothes. Due to contact and gravity, clothes rarely show their original shape. In this case, edge tracing is important in object recognition. In this paper, it is used to spread clothes, which is important in folding or hanging clothes out to dry. Much research has been done on deformable object manipulation but very little on clothes manipulation. Even that on clothes manipulation is largely theoretical rather than practical. This paper proposes a practical research on towel spreading as an example of clothes manipulation using sensor-based edge tracing. Spreading clothes basically involves holding two corners of the clothes to spread or fold them. The problem is finding the appropriate corners. Vision sensors help find corners, but corners are not necessarily visible or exposed to the camera, causing the robot to hold the clothes unsatisfactorily. Even when a camera detects a corner, the corner may not be appropriate. By using tracing manipulation to find the second corner, this paper will prove that the second corner found is that next to the initially found corner and not the one apposite it (**Fig. 1**). The usage of different types of grippers designed to improve the reliability of the tracing process is also discussed in this paper.



(i) Example of an improper clothes spreading
(ii) Example of a proper clothes spreading

Fig. 1 Problems in clothes spreading

2. Towel spreading algorithm

Fig. 2 shows the flow for proposed towel spreading. After a towel is picked up randomly with one gripper (gripper A) and held up, one of the four corners is usually the closest point to the ground. This is used to locate one of the corners using images by the CCD camera. The towel background is subtracted, leaving the towel outline. This is done by subtracting two images of the towel -- the second taken after moving the towel slightly downward. The resulting image is then binarized. After noise is reduced, the binarized image is labeled and the lowest point within labeled data with more than a certain number of pixels is recognized as a corner.

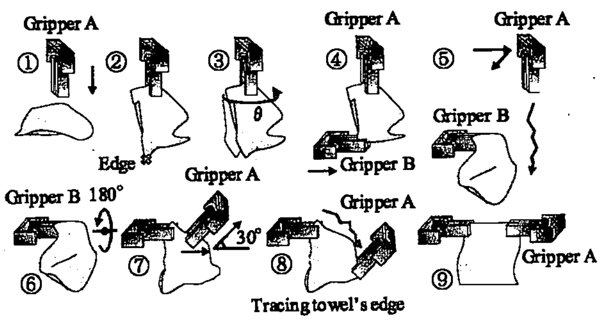


Fig. 2 Proposed towel spreading algorithm

Gripper A then rotates at the wrist to find the best angle for the second gripper (gripper B) to grip and hold the corner. Coordinates of the corner are calculated after the best position is found. Because only one fixed CCD camera is used, motion stereo is used to calculate the distance of the towel corner from the camera using two images of the corner at different locations and comparing the displacement seen from the camera to actual displacement. After corner coordinates are calculated, gripper B grasps the corner. The success of the attempt is determined using infrared sensors. Since our focus is the tracing manipulation, we will not elaborate on the finding of the first corner.

After gripper B grasps the first corner, gripper A releases the towel it is holding and starts tracing the edge of the towel from beneath the first corner, and stopping once it reaches a second corner. Refer to Section 4 for details on tracing. The robot spreads the towel by holding both corners. In case the spreading failed, the robot can be programmed to repeat the process from any point desired. This is possible due to feedback from infrared and vision sensors.

3. Clothes Spreading System

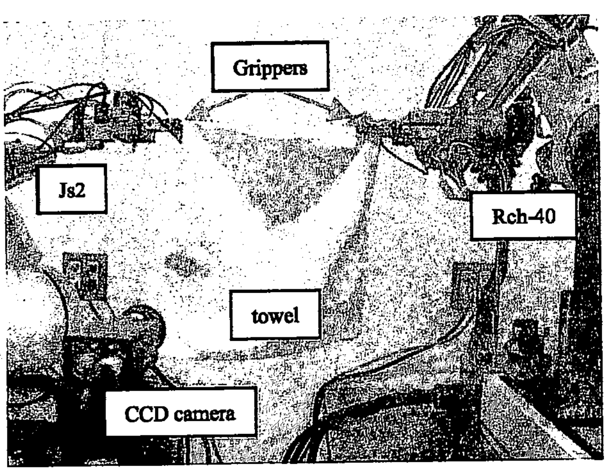


Fig. 3 Scene on clothes manipulation

In this research, we use two robot arms, Js2 (Kawasaki Heavy Industries) with 6 degrees of freedom (DOF) and Rch-40 (Yamaha) with 5 DOF. Both arms withhave grippers designed for clothes manipulation with force sensors to detect force applied to fabric and infrared sensors to detect whether the fabric is in the gripper or not. A CCD camera that detects and confirms corners is located in front of the two robot arms (**Fig. 3**). Origins of the Js2 and Rch-40 are located 0.35m in front, 0.44m to the left and 0.21m to the right of the CCD camera respectively. Images taken by the CCD camera are in 8-bit gray scale and 640x480 pixels in size. A TRV-CPW5 image processing board (Fujitsu) speeds up image processing. Grippers designed to improve the reliability of the tracing process is attached to the Js2.

4. Edge Tracing Manipulation

After Js2 gripper is positioned at the edge of the towel, it will start tracing the edge of the towel by smartly using the feedbacks from the infrared sensors. Let's assume that the RCH-40 gripper is grasping the first corner. After Js2 gripper is positioned at the edge of the towel just beneath the first corner, it will start tracing the edge of the towel by smartly using the feedbacks from the infrared sensors (**Fig. 4**). This movement pattern is based on the feedbacks from Js2 gripper's infrared sensors and should enable Js2 to find a corner next to the one being held and not the one across it. The state transition diagram of the tracing manipulation method is shown in **Fig. 5**. The movement of the Js2 gripper during tracing can be shown in the form of a vector **u** (tracing vector, direction only) and can be written as follows:

$$\mathbf{u} = (-\sin\theta, -\cos\theta),\ |\mathbf{u}| = 1 \qquad (1)$$

θ is the Js2 gripper angle from the z-axis on the xz-plane (Js2 gripper orientation). From Equation (1), Js2 gripper orientation is also an important factor during edge tracing. The gripper must be set 90deg from the trace direction in order to fully use the feedback from the infrared sensors. The tracing vector **u** will change every time the feedback changes from pattern A to B and vice versa or after Js2 gripper has traced a certain distance of the towel (tracing distance Δr). Tracing distance Δr is the maximum dislocation for Js2 gripper before it rotates in order to quicken the process of moving outward or inward the towel. In case the feedback turns to or stays at pattern A, Js2 gripper will rotate counter clockwise so that the gripper will be able to trace inwards the towel. If the feedback pattern turns to or stays at pattern B, Js2 gripper will rotate clockwise so that the gripper will be able to trace outwards the towel. The new tracing vector $\mathbf{u}_{new}$ can be written as follows:

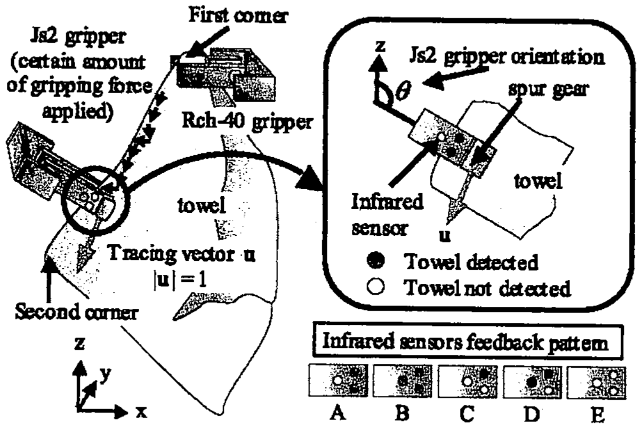


Fig. 4 Important elements during edge tracing

$$\mathbf{u}_{new} = (-\sin(\theta - \alpha), -\cos(\theta - \alpha)) \qquad (2)$$

$$\mathbf{u}_{new} = (-\sin(\theta + \alpha), -\cos(\theta + \alpha)) \qquad (3)$$

α is the rotation angle. Equation (2) is the new tracing vector for pattern A and Equation (3) is the new tracing vector for pattern B. The appropriate rotating angle and also the tracing distance is decided through experiment. Force control is applied to Js2 gripper during tracing process using the following equation:

$$P = k(F - F_0) \qquad (4)$$

P is the current reference value for the motor, F is the measured force from the strain gages, F_0 is the target force and k is a gain. It is important to apply an appropriate amount of force to the Js2 gripper during edge. Applying too much force may result in the gripper dragging the towel, not tracing it. But if too little force is applied, the towel may slip away from the gripper due to gravitational force. Js2 will trace the edge of the towel until infrared sensors feedback becomes pattern C or D, indicating that Js2 is holding a possible corner, and corner confirmation process will take place. CCD camera is also used to check if a corner is reached or not. If the second corner is reached and confirmed, Js2 gripper will firmly grasp the corner and the towel is spread. One of the most difficult parts in tracing is maintaining the Js2 gripper at the edge of the towel is difficult and dangerous because the towel may slip away form the

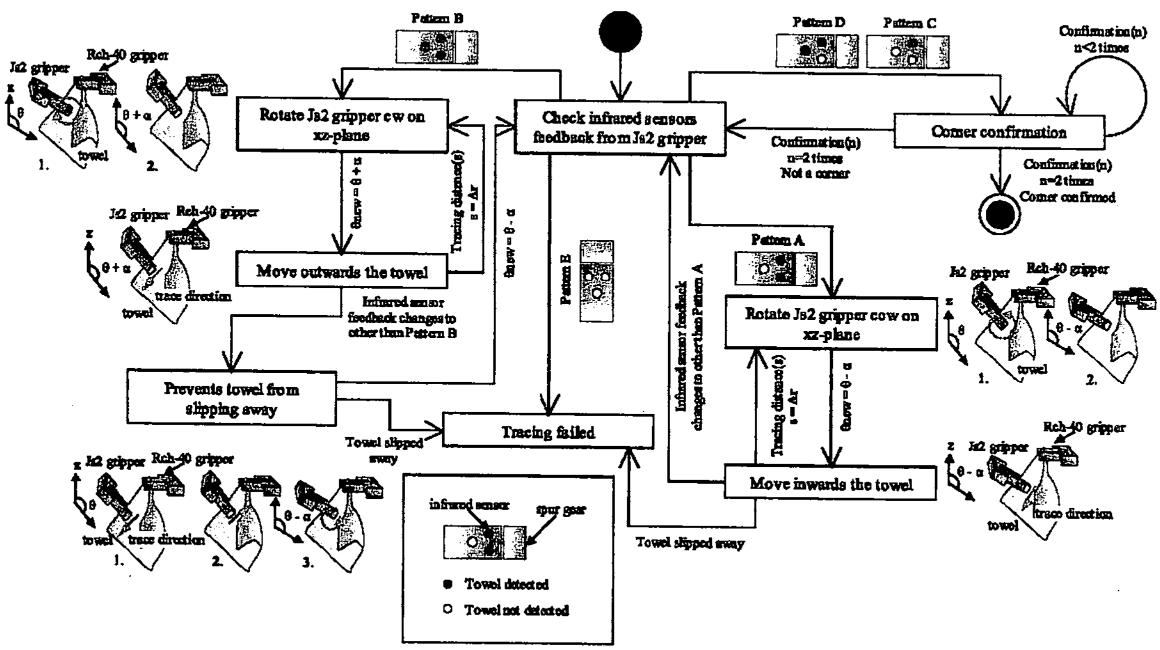
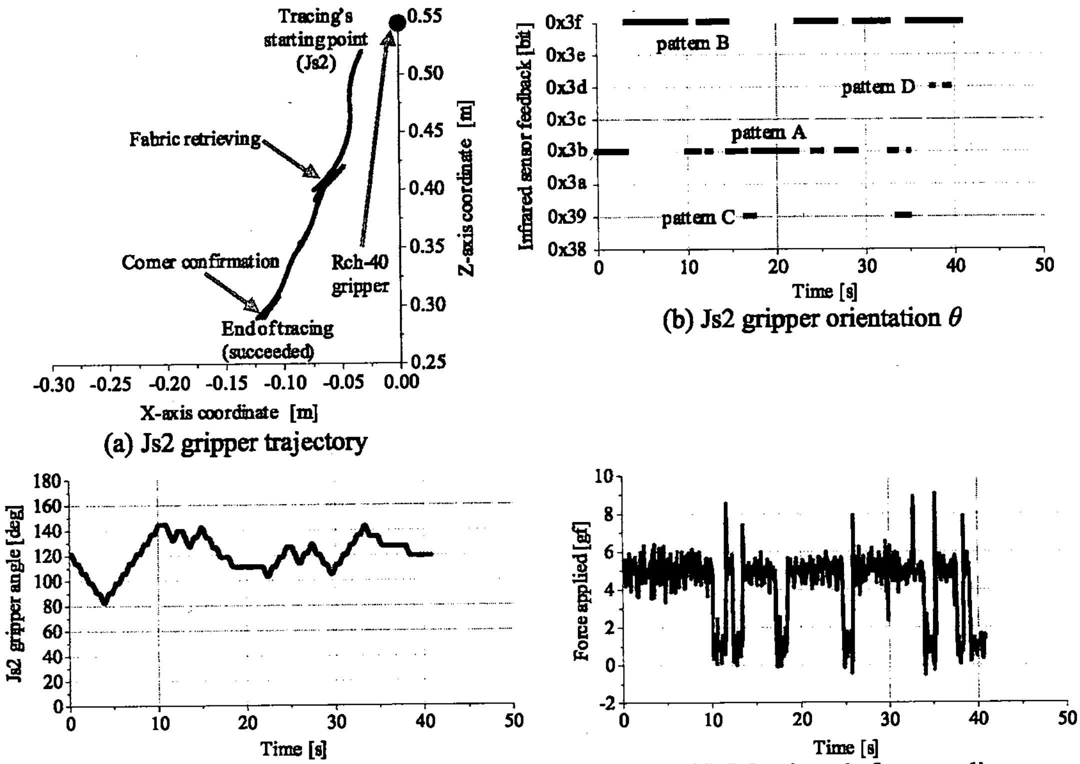


Fig. 5 State transition diagram for tracing manipulation

gripper. In order to prevent this, fabric retrieving process is performed when the Js2 gripper is moving outwards and the feedback pattern changes from pattern B to pattern A.

5. Experimental Results

Experiments were conducted to evaluate the towel spreading algorithm. Edge tracing experiments were also conducted to evaluate the edge tracing algorithm and also the designed grippers. Each gripper has its own ideal tracing manipulation algorithm. **Fig. 6** shows a sample data for tracing experiment using gripper with roller mechanism at the fingertips. **Fig. 7** shows the scenes during towel spreading.



(a) Js2 gripper trajectory

(b) Js2 gripper orientation θ

(c) Js2 gripper's infrared sensors reading

(d) Js2 gripper's force reading

Fig. 6 Experiment data for edge tracing by Js2 with spur gear tips rotating ($\alpha = 5deg$, $\Delta r = 5mm$, $P = 5gf$, speed of tracing = $0.02m/s$)

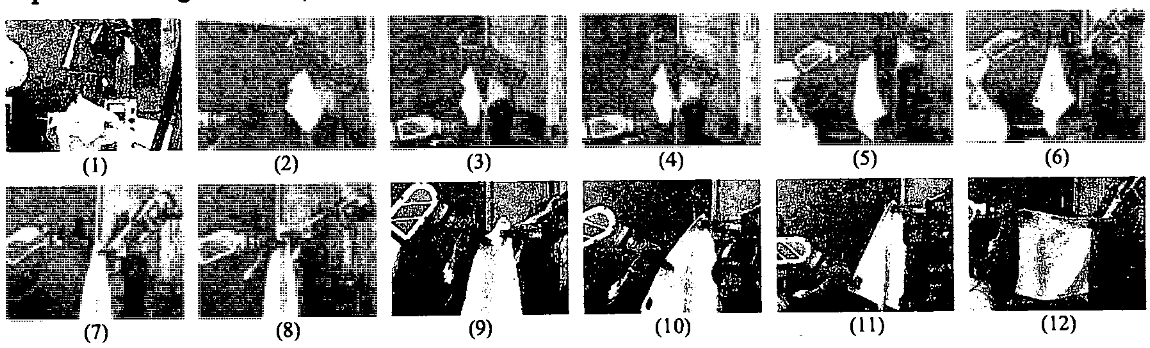


Fig. 7 Scenes during towel spreading

6. Conclusions

A method for towel spreading using a unique edge tracing method by unique grippers is presented. The combination of infrared sensors feedbacks, force sensors for firm gripping of the fabric and the help of the CCD camera from time to time have proven to be important in fabric spreading especially in fabric tracing manipulation.

学位論文審査結果の要旨

平成 18 年 8 月 2 日に第 1 回学位論文審査委員会を開催し，提出された学位論文及び関係資料に基づき論文内容を詳細に検討した．さらに，平成 18 年 8 月 2 日に行われた口頭発表後に，第 2 回学位論文審査委員会を開き，協議の結果，以下のように判定した．

ロボットアームによる柔軟物操作は，近年でもまだまだ未解決の部分が多い．衣類はその１つであるが，形が変わりやすいためマニピュレーションが困難であり，ロボットで衣類を器用に操った研究は非常に少ない．本研究では，ロボットで衣類（タオル）を展開する現実的なマニピュレーション手法について研究を行っている．タオルを展開するのに，２台のグリッパ付き多関節ロボットアームを用い，タオルの１つの角を見つけてグリッパで把持し，そこからもう１つのグリッパを衣類の端に沿って移動させて隣の角を把持する「なぞり動作」を行わせることを提案している．グリッパの把持力を検出する高感度力センサ，グリッパ間の衣類の有無を検出する光センサ，及び，CCD カメラからのセンサ情報を統合して「なぞり動作」をスムーズに行う制御手法を各種，検討した．さらに，衣類をマニピュレーションしやすくするため，ローラー付きのグリッパとインチワーム型のグリッパを新しく考案・試作し，それらにより，信頼性の高いタオルの展開作業を実現した．

以上のように，本研究は，ロボットによる柔軟物のマニピュレーションに関して，多くの有用な知見を得ており，ロボット工学における価値が非常に高いと評価できる．よって，本論文は博士（工学）に値するものと判定する．