Figure 6. Pre-determined movement patterns tracing flowchart
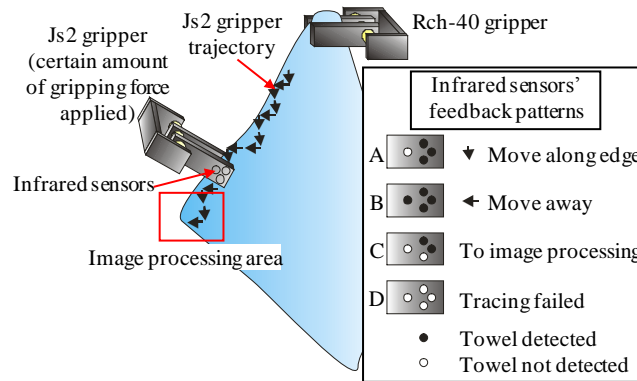
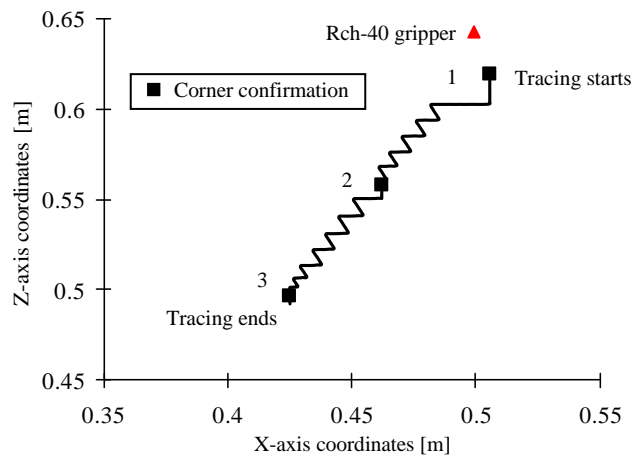Figure 7. Infrared sensors feedback pattern during tracing

Figure 8. Js2 trajectory during pre-defined movement patterns tracing

d.   Edge Tracing using Real-time Path-Planning based on Image

Edge tracing using pre-determined patterns has been proven to be successful but the path trajectory is usually not optimized. This is because the Js2 moves in zigzag pattern instead of a straight line. In order to further optimize the path and fasten the process, a real-time path-planning method based on image is proposed. The method is based on the image taken during corner confirmation. The position of the possible corner is first determined from the image (X_c,Y_c,Z_c). The position of the Js2 gripper tip is also obtained (X_j,Y_j,Z_j). Since the clothes are airborne during manipulation, the possible corner will usually be on the same XZ-plane as the gripper tip. This means the path-planning will be based on 2 dimensional calculations instead of a more complex 3 dimensional calculations. The shortest path, S is then generated between (X_c,Z_c) and (X_j,Z_j) using the following equation:

$$S = \sqrt{(X_c - X_j)^2 + (Z_c - Z_j)^2} \tag{1}$$

Since the real-time tracing is based on velocity vectors $\mathbf{V_X}$, $\mathbf{V_Y}$, $\mathbf{V_Z}$, where $\mathbf{V_Y} = 0$, the magnitude of the tracing velocity vector $\mathbf{V}$ should be determined based on the following equation:

$$|\mathbf{V}| = \sqrt{|\mathbf{V_x}|^2 + |\mathbf{V_z}|^2} \tag{2}$$

If the magnitude of the velocity $\mathbf{V}$ can be pre-determined, the following can be determined:

$$|\mathbf{V_x}| / |\mathbf{V_z}| = (X_c - X_j)/(Z_c - Z_j) = \tan\theta \tag{3}$$

where θ is the angle between vectors $\mathbf{V}$ and $\mathbf{V_Z}$. Based on equations (2) and (3), the magnitudes of the vectors $\mathbf{V_X}$ and $\mathbf{V_Z}$ can be determined.

$$|\mathbf{V_z}| = |\mathbf{V}| / \sqrt{1 + ((X_c - X_j)/(Z_c - Z_j))^2} , \quad |\mathbf{V_x}| = |\mathbf{V_z}| \times (X_c - X_j)/(Z_c - Z_j) \tag{4}$$

The Js2 gripper can then trace the edge of the clothes based on the inputs from equations (1) and (4). The direction of tracing during pattern A is dependent upon equation (2) instead of a fixed

direction used in the previous method. For other feedback, the actions taken will be the same. Force control is applied to the Js2 gripper during tracing. The gripper will continue to trace the edge until either the distance S is covered or until the infrared sensors feedback changes to other than patterns A and B. If any of these conditions are met, corner confirmation process using vision sensor will take place. A new possible corner is then determined and the tracing process continues until the second corner is found. The tracing flow is shown Figure 9. Constant force control is applied to the Js2 gripper during tracing.
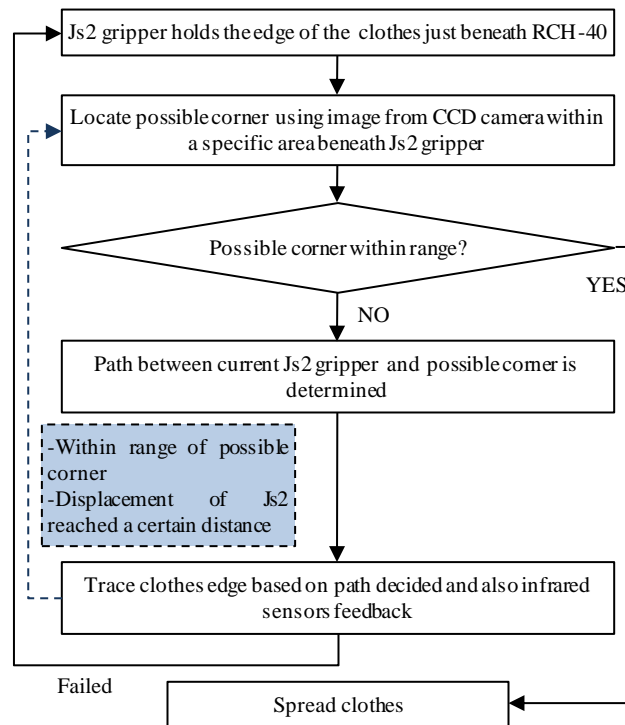
Figure 9. Flowchart for real-time path-planning tracing

VI. EXPERIMENTAL RESULTS

Tracing experiments were conducted to evaluate the proposed path-planning algorithm. Rectangular shaped towel (properties: color white, size 32cm x 32cm, thickness 2.28mm, mass per unit area 0.037g/cm², static coefficient of friction μ 0.625, stretch rate 0.005mm/gf) is used in all experiments. All experiments were started with the Rch-40 gripper holding a corner of the towel. The range for image processing during corner confirmations is set at 100x80 pixels with the right topmost point 10 pixels below the end of Js2 gripper on the screen. One pixel

corresponds to 0.94mm of length at 0.35m in front of the camera. Real time control is applied to Js2 robot during tracing where the magnitude of the tracing velocity vector **V** is set at 0.02m/s and S is set to 40mm. Force control is set at 20gf for Js2 gripper. For each setting, the experiment is repeated 20 times.

Figure 10 shows example data obtained from a successful tracing experiment. From Figure 10(a), it can be observed that Js2 gripper trajectory is very much optimized since the trajectory very much heading in a straight line towards the possible corner. Feedback from strain gages and infrared sensors on the Js2 gripper are shown in Figure 10(b) and Figure 10(d) respectively. From the feedback, it can be said that the force control was successful and the gripper traced near or along the edge of the towel all the time. Figure 10(c) shows the image taken by the vision sensor during corner confirmation. Figure 11 shows the snapshots taken during edge tracing.
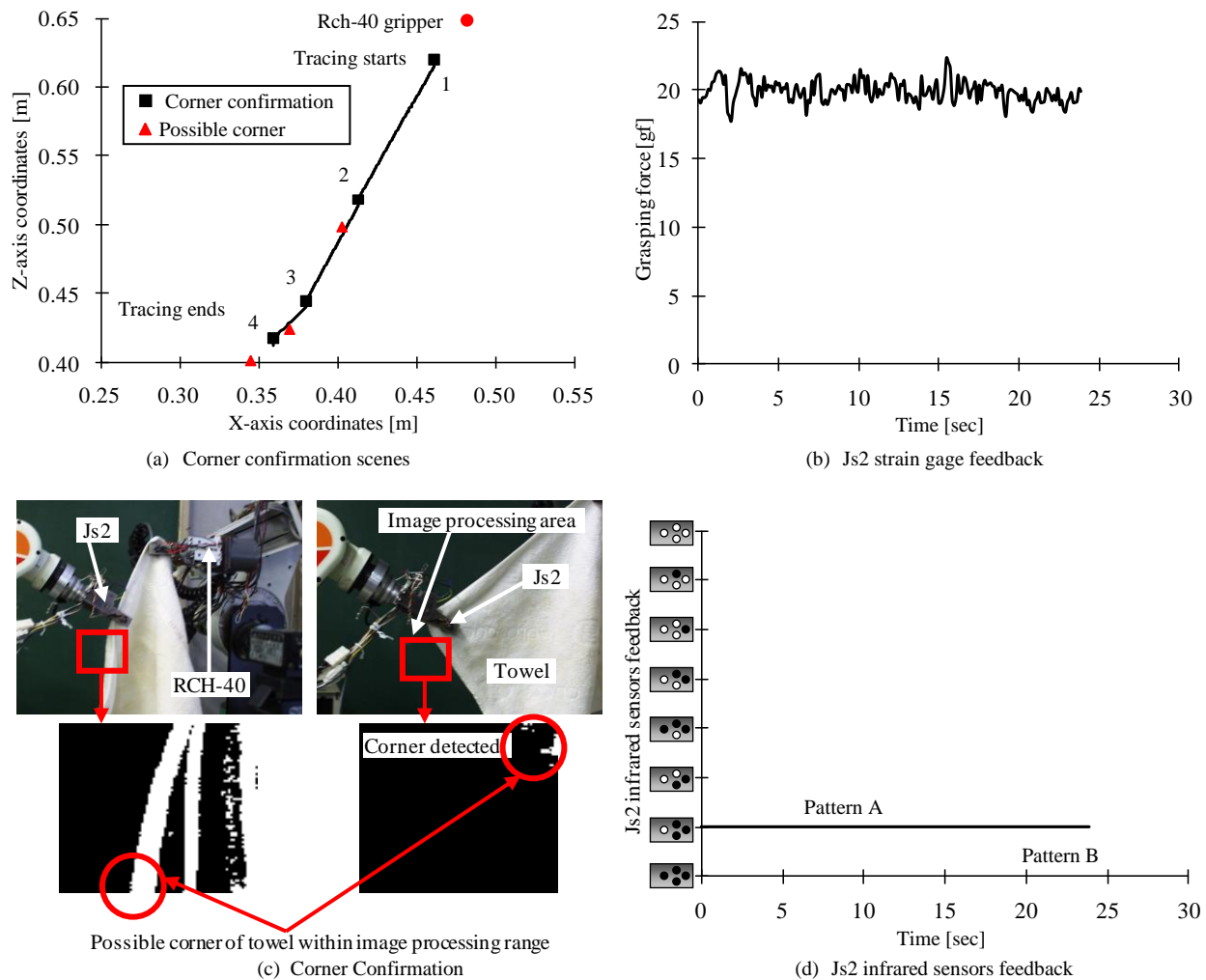
(a) Corner confirmation scenes

(b) Js2 strain gage feedback

(c) Corner Confirmation

(d) Js2 infrared sensors feedback

Figure 10. Real-time path planning tracing experimental data

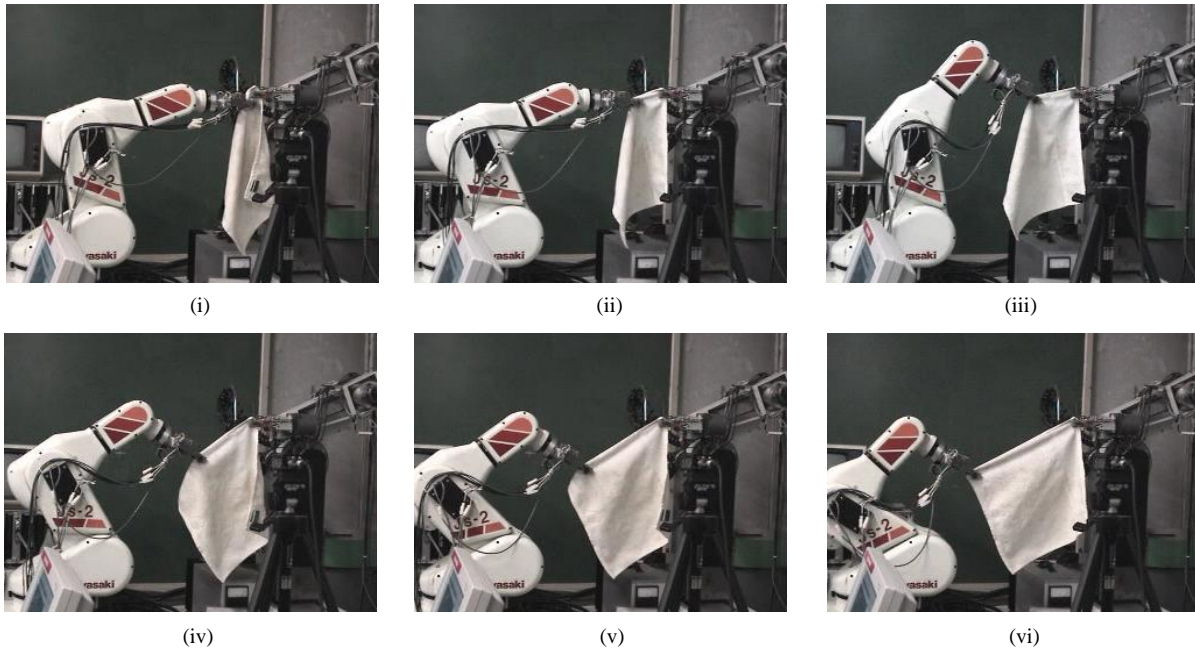|		
(i)	(ii)	(iii)
(iv)	(v)	(vi)

Figure 11. Scenes during edge tracing

The time required to find the second corner has been reduced significantly compared to the pre-defined movement patterns tracing. But, the reliability is not good enough. The reason is because the target point (X_c, Y_c, Z_c) is a corner or possible corner point, and the line connecting the current position of Js2 gripper and the target point is the edge of the towel. This resulted in the gripper tracing too close to the edge which sometimes lead to the towel slipping away.

In order to increase the success rate, the target point is set slightly inward the towel (X_c', Y_c, Z_c) where X_c' is 10mm or 20mm inward the towel compared to X_c. It is observed that the success rate has increased when the target point is moved inward but the manipulation time increases. Sample trajectory data taken during these experiments are shown in Figures 12 and 13 respectively. Table 1 shows the comparison of the results for all the experimental setup including the pre-determined movement patterns method. It can be concluded that the real-time path planning method is generally faster and by setting the target point inwards increases the reliability of the method
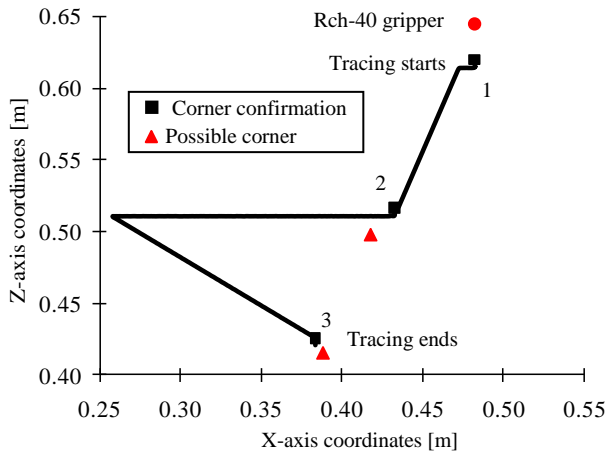
Figure 12: Js2 trajectory during real-time path-planning with target point set at $(X_c+0.01, Y_c)$
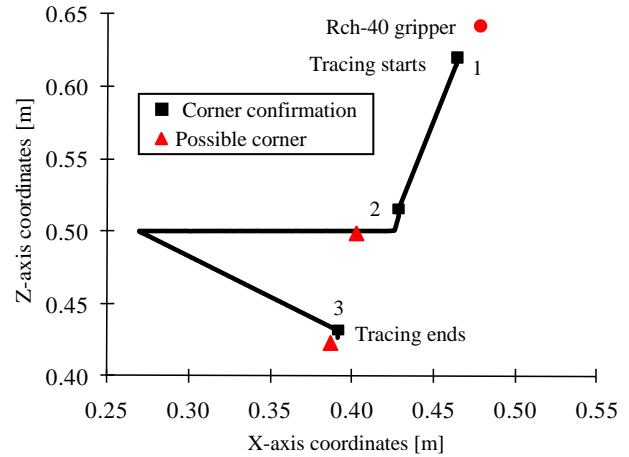

Figure 13: Js2 trajectory during real-time path-planning with target point set at $(X_c+0.02, Y_c)$

Table1. Data on performance of proposed tracing algorithm

Tracing method/setup	Running time average ($|\mathbf{V}| = 0.02$ m/s)	Reliability (First try)
Pre-defined movement patterns tracing (benchmark)	41.0 sec	70%
Real-time path planning tracing - target point (X_c,Y_c) -	33.3 sec	45%
Real-time path planning tracing - target point $(X_c+0.01,Y_c)$ -	36.1 sec	60%
Real-time path planning tracing - target point $(X_c+0.02,Y_c)$ -	37.8 sec	70%

All failures are recoverable since the infrared sensors can detect whether the towel is inside the gripper or not. The process can then be repeated until the second corner is successfully grasped, as shown in Figure 9.

VII. CONCLUSIONS

A paper discussing the real time path planning tracing for clothes manipulation is presented. The method has been proven to successfully optimize the path taken for tracing for clothes to find a second corner for spreading or unfolding purposes. This leads to a shorter and faster tracing time which is important to speed up clothes folding process as a whole. The slight setback was initially the method lacked reliability but by setting the target point to be slightly inward solved this.. Further studies can be conducted to further improve the reliability and speed. On the other hand, all processes can be repeated as all the failures are detectable by the robot. Other future works include implementation of the method to curvy shaped fabrics or clothes to further study the robustness of the proposed algorithm.

ACKNOWLEDGEMENT

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