REAL-TIME PATH PLANNING TRACING OF DEFORMABLE OBJECT BY ROBOT

Khairul Salleh Mohamed Sahari[1, 2], Hiroaki Seki[2], Yoshitsugu Kamiya[2], Masatoshi Hikizu[2]

[1]Department of Mechanical Engineering,

Universiti Tenaga Nasional, Jalan IKRAM-UNITEN,

43000 Kajang, Selangor, Malaysia

[2]School of Mechanical Engineering, Kanazawa University,

920-1192 Kanazawa, Ishikawa, Japan

Emails: khairuls@uniten.edu.my

Abstract- Edge tracing is considered important for deformable object manipulation in order to spread and reveal the original shape of an object before it can be sorted. This paper proposes a unique real-time path-planning tracing method for clothes manipulation by robots. Tracing in this paper context involves tracing the clothes edge, with the robot arm movement based on the calculated path and feedback from sensors. Using tracing method to find a second corner has been proven to be efficient in finding a second corner next to the first corner and not apposite it, resulting in the robot properly spreading the clothes. Adequate force control is also applied to the gripper during tracing so that it doesn't grip the clothes too hard or vice versa which can affect the performance of the robot. Vision sensor is used from time to time to check whether the static gripper has reached the second corner or not. Practical experiments were conducted to evaluate the proposed method. Experimental results have demonstrated the uniqueness and effectiveness of the proposed method.

Index terms: Home service robot, path-planning, deformable object manipulation, image processing, sensors.

I. INTRODUCTION

Robotics is becoming more and more common nowadays. A lot of researchers are focusing on robotics development in various areas including space exploration, underwater exploration and rescue mission. Toda and Capi proposed the usage of new type of ultrasonic gas molecule concentration sensor for rescue robotics [1]. Some researchers also developed robots that can play sports or musical instruments. Jabson et-al developed an autonomous golf playing micro robot equipped with global vision and fuzzy logic controller[2].

In recent years, the focus on home robotics has increased significantly. The task of manipulating deformable objects such as papers, plastics and clothes is a challenge to the current robotics development. This is because unlike rigid objects, deformable objects manipulation requires dexterous handling. Deformable objects or so-called soft objects can be divided in to two categories which include flexible, mostly thin, fine objects capable of elastic deformation and soft objects easily crushed such as soft fruits or animals [3]. Clothes manipulation falls under the first category. A few researchers focus on the clothes, fabric or garment manipulation by robot since it is useful for the textile industry as well as for the development of home service robot. Brown et-al proposed an algorithm to animate the deformable objects in real time [4]. A fast space-time optimization method was suggested by Barbič et-al to reduce the time needed in mass-spring model simulation [5]. To recognize the clothes state before manipulation, Kita et-al proposed a deformable model driven method for clothes handling by using two manipulators while stereo camera observes the appearance of hanging clothes to estimate the clothes state based on comparison between the hanging clothes with the possible 3D shapes of clothes in the manipulator module [6]. Saxena et-al presented an algorithm to identify the good grasping point of an object by gathering few points in each images captured from different sides of the object [7]. In clothes manipulation, Osawa et-al presented a system to fold clothes by utilizing the collective behavior of the tools and robots [8]. Kaneko et-al suggested a strategy to isolate one clothes from the washed pile by differentiating the colour of the clothes based on colour information of the image before the robot unfolds and fold the clothes by applying several repeated process loop [9]. Gibbons et-al meanwhile uses the visual system to identify possible grasp locations which are generally the edges or corners of clothes from a pile of crumpled clothes [10]. Besides clothes, some researchers concentrate on paper manipulation. Balkcom et-al studied on how to fold origami using robot [11].

But many researchers doing practical research in clothes manipulation focuses a lot on usage of special tools. This paper discusses a method of clothes spreading using two manipulators with very minimal assisting tool. The purpose of the study is to determine an algorithm for clothes handling for home service robots. Usage of special tools is not recommended since the manipulators must also be able to handle perform other household tasks as well. The best method to handle clothes is by mimicking how human beings handle them. This is where edge tracing plays an important role. Usually we will trace the edge of the clothes to spread or fold them [12]. This edge tracing method is adapted into this research. This paper discusses the current method developed for edge tracing for clothes spreading before a new and more optimized using real-time path planning method is suggested. In order to prove the theory, practical experiments are also conducted.

II. CLOTHES MANIPULATION METHOD IN GENERAL

Normally after laundry and dried, clothes are usually piled together. Usually, we would first separate clothes that are folded from the ones hanged. For clothes that are folded, an item is picked up from the pile and it is then spread before it is folded and stored. During folding, usually the type, shape and size play an important role in determining how we fold the clothes. This is the sorting process. Before folding, the clothes are spread in order to reveal its normal shape. In clothes handling by robot, this spreading process is usually the challenging part because of the infinite state of the clothes depending on the external force etc. In order to properly spread clothes, the robot must also hold two side by side corners of the clothes. Failure to do this might result in incorrect spreading of clothes. Figure 1 shows the flowchart of the proposed clothes handling procedure for home service robots.

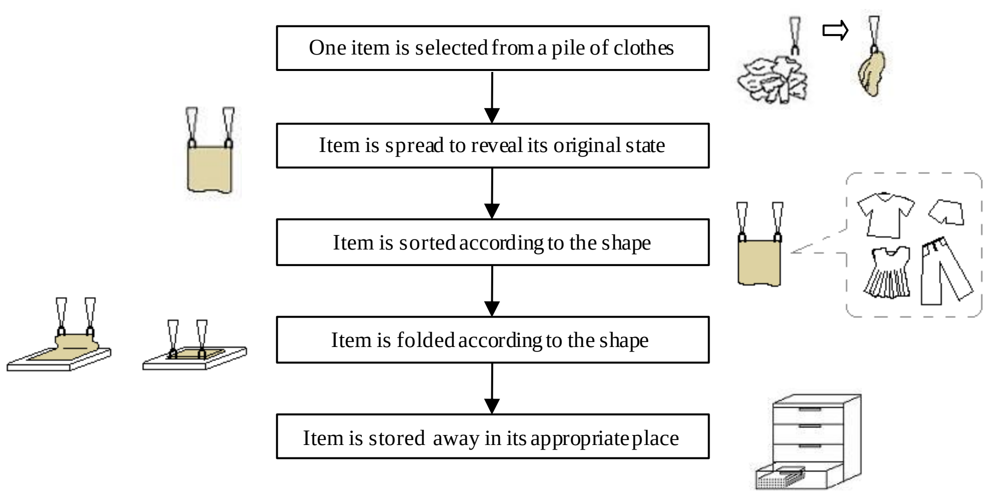

Figure 1. Flowchart of clothes manipulation process

III. CLOTHES SPREADING PROCESS

Spreading process is the most difficult process in clothes handling since the clothes can be in any state before spreading due to the infinite degree of freedom. The algorithm proposed in this paper is based on edge tracing method. First, one of the corners of the clothes is determined by using image from vision sensor. Due to gravity, after one clothes is picked up, one of the corners will usually be the lowest point in the image seen. The robot will then grasp the corner using one hand. Another hand will trace the edge of the clothes starting from the grasped corner to find another corner that is next to the first corner. Once the second corner is found, the robot will spread both hands and the clothes will then be spread. The flow of the spreading process is shown in Figure 2.

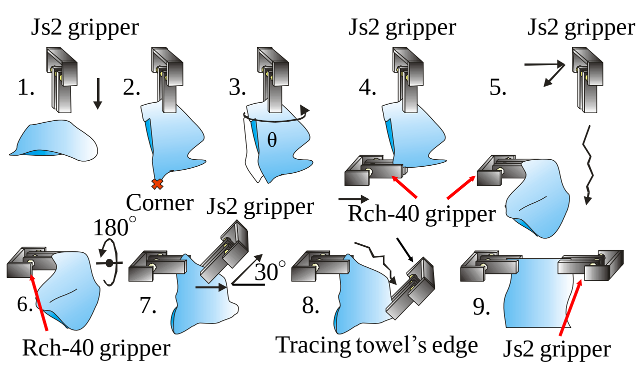

Figure 2. Clothes spreading algorithm

IV. CLOTHES MANIPULATION SYSTEM

Figure 3 shows a scene during clothes manipulation. In this research, one Js2 (Kawasaki Heavy Industries) with a 6 degree of freedom (DOF) and one RCH-40 (Yamaha) with a 5 DOF are used. Both are articulated robotic arm and are equipped with customized robot grippers designed for clothes manipulation. A vision sensor (Tokyo Denshi Kogyo CCD camera with a 6mm focus range and a focal ratio of 1:1.4) is located in a fixed position in front of the two robots. The images taken by the CCD camera are in 8-bit grayscale format and 640x480 pixels in size. An image processing board TRV-CPW5 (Fujitsu) that has image tracking function is used to speed up image processing.

Robotic grippers used are open-close grippers controlled by a DC servo motor equipped with rotary encoder from Maxon motors (18V, 3.0W, lift-torque 10.8mNm, max rpm 16000rpm) via spur gears and two-way ball screw with a 1mm lead. The encoder's resolution is 100pulse/rotation. The unique part about the gripper compared to other grippers in the market is the thin part on both fingers that are sensitive to changes in force (Figure 4). Strain gages are attached on both sides of the thin part of a finger where the strain value is determined from the whetstone bridge through a strain amplifier. When the gripper closes, the fingers will push each other backward and the average strain from two fingers is used to calculate the force applied. This is useful in maintaining the grasping force during tracing. A thick part just behind the thin part acts as a stopper in case of excessive force to prevent the thin part from failure. 4 sets of infrared sensor (Toshiba) are embedded onto the fingers to give information on whether clothes or fabric is inside the gripper or not. Based on the task, the thin part is designed to withstand 558gf of force before it touches the thick part behind. Maximum opening is 35cm.

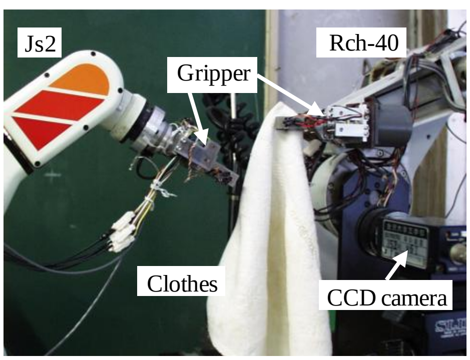

Figure 3. Clothes manipulation system

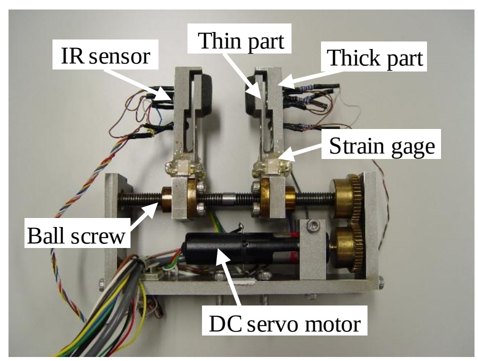

Figure 4. Robotic gripper for clothes manipulation

V. EDGE TRACING IN FINDING THE SECOND CORNER

In this research, after the robot has found and successfully grasped the first corner, it will search for the corner next to the first corner in order to spread the towel correctly. Although the usage of vision sensors plays a big role in helping to find a corner [13], the corners of the clothes are not necessarily visible or exposed to the camera. And even if the camera does detect a corner, it doesn't mean that the corner is the right one. The robot may end up not holding a true corner of the clothes or holding a wrong corner thus resulting in improper spreading of the clothes. Edge tracing method on the other hand would not just enable the discovery of the second corner but also ensures that the corner is the one next to the first corner [12]. Other merits of using this method are the process can be performed in the air, so a working platform is not necessary [8], [13], [14], besides being robust to most shapes and sizes. Before the edge tracing manipulation can take place, the tracing gripper (Js2) must be holding the edge of the clothes just beneath the first corner.

a. Preparations Before Edge Tracing

Before edge tracing, it is important that Js2 gripper (Gripper A) grips the edge of the clothes at the starting point of the tracing manipulation. This is because if the starting point is not the actual edge of the clothes, the robot will most probably fail in finding a true corner. There is a possibility that the edge Js2 gripper grips is a folded edge. Experiments have revealed that the edge nearer to the corner being grasped by Rch-40 gripper (Gripper B) to be less or not folded. Js2 gripper is programmed to firmly grip the edge of the towel 2cm below Rch-40. There are two important points during the edge gripping process. The first one is to make the gripper grip near the edge, not too deep inside. The second one is making sure that the gripper unfolds creases in the process if there are any. The reason for this is because the crease line will be considered as the edge of the towel by the robot, which can lead to Js2 gripper finding an incorrect corner. First, Js2 gripper is positioned just beneath the Rch-40 gripper. The opening of the Js2 gripper is set at 30mm. Then after firmly grasping the clothes by applying force control to the gripper, Js2 will move away from the towel and stops reaching the edge, judged by the innermost infrared sensor feedback of the Js2 gripper. The tracing preparation process is shown in Figure5.

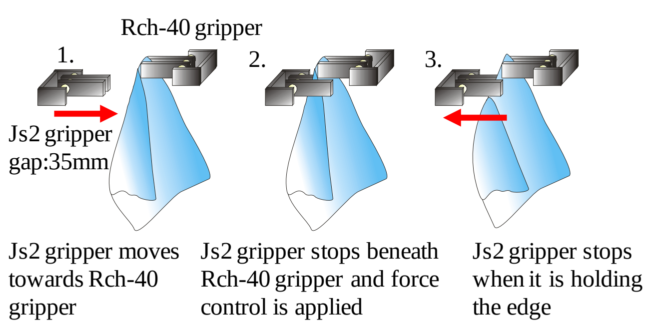

Figure 5. Tracing preparations

b. Edge Tracing using Pre-determined Movement Patterns

The basic idea in edge tracing here is to apply a certain amount of grasping force while the gripper traces the edge of the clothes based on infrared sensors feedback. From time to time, vision sensor will check the progress, whether the next corner has been found or not. Certain feedback patterns also tell that possible corner has been reached. The flow of the tracing manipulation is shown in Figure 6.

First, combination of the feedback from all four sensors is studied and then the best tracing algorithm using the sensors feedback is proposed. The combination of the feedback and the tracing movement is shown in Figure 7. Feedback A is where Js2 gripper is holding the edge of the towel. The robot will try to find and keep the feedback at this pattern. Feedback B indicates that Js2 is holding deep into the clothes and not the edge. Js2 will move away from the clothes until the feedback turns back to feedback A. Feedback C indicates that Js2 is holding a possible corner. The robot will check whether a corner is reached or not using the vision sensor. Feedback D shows that Js2 gripper is not holding any part of the corner or the feedback is unlikely. The robot will assume that the tracing manipulation has failed and will restart the tracing process all over again.

Based on experiments, the movement of the Js2 gripper will be slightly inward the towel along the edge instead of moving exactly along the edge of the clothes. This reduces the possibility for the clothes to slip. Since the gripper will gradually move inwards, infrared sensors feedback will change from A to B, meaning that the gripper is no longer near the edge. Js2 gripper then moves away from the towel until the feedback turns back to A. This will result in the tracing trajectory being in zigzag pattern. Experiments have proven this fact. Figure 8 shows the trajectory of Js2 gripper during tracing.

c. Corner Confirmation during Tracing

Corner confirmation process will be based on two criteria. First, it is based on the feedback of the infrared sensors. Feedback C indicates that a possible corner is reached. Corner confirmation process will also take place after JS2 has traced a pre-determined distance, S. An image (100x100 pixels) where the top right corner is the position of the gripper end is captured and analyzed (Figure 7). If a corner is reached or the corner is close enough to the JS2 gripper (20mm or lesser in distance), the tracing process will stop and the robot will spread the clothes.

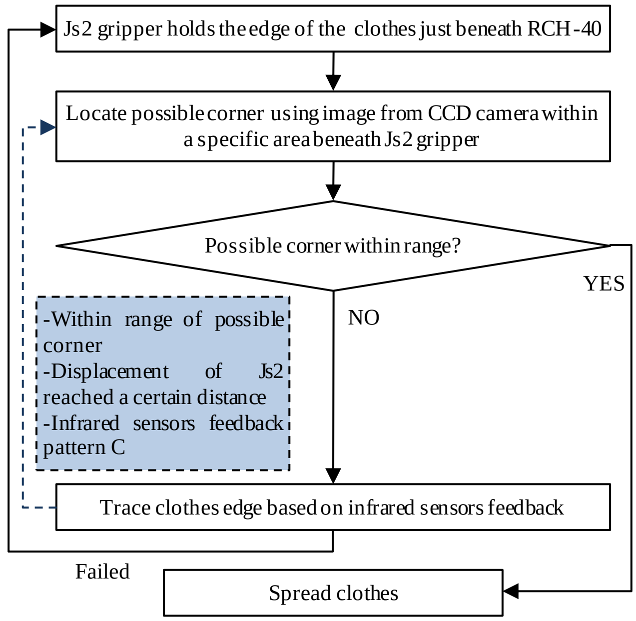

Figure 6. Pre-determined movement patterns tracing flowchart

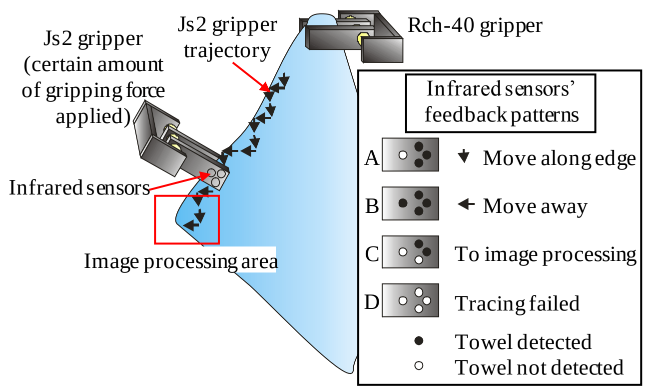

Figure 7. Infrared sensors feedback pattern during tracing

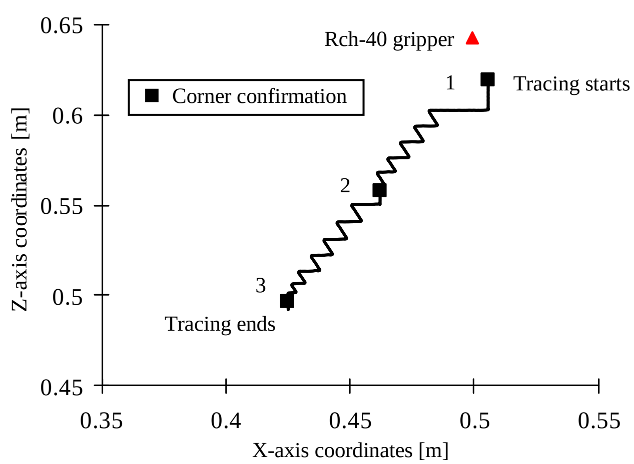

Figure 8. Js2 trajectory during pre-defined movement patterns tracing

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:

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

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:

$$|\mathbf{V}| = \sqrt{|\mathbf{V_x}|^2 + |\mathbf{V_z}|^2} \quad (2)$$

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

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

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.

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

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.

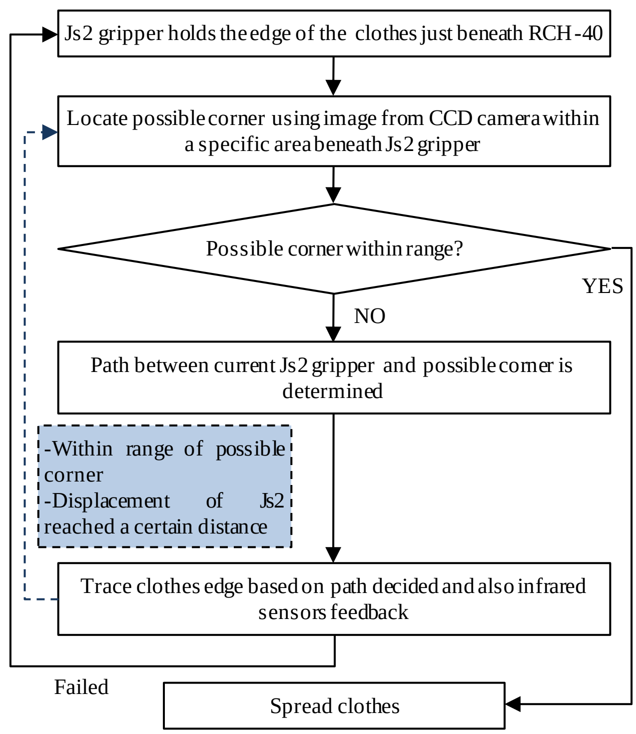

Figure 9. Flowchart for real-time path-planning tracing

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 $0.037 g/cm^2$, 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.

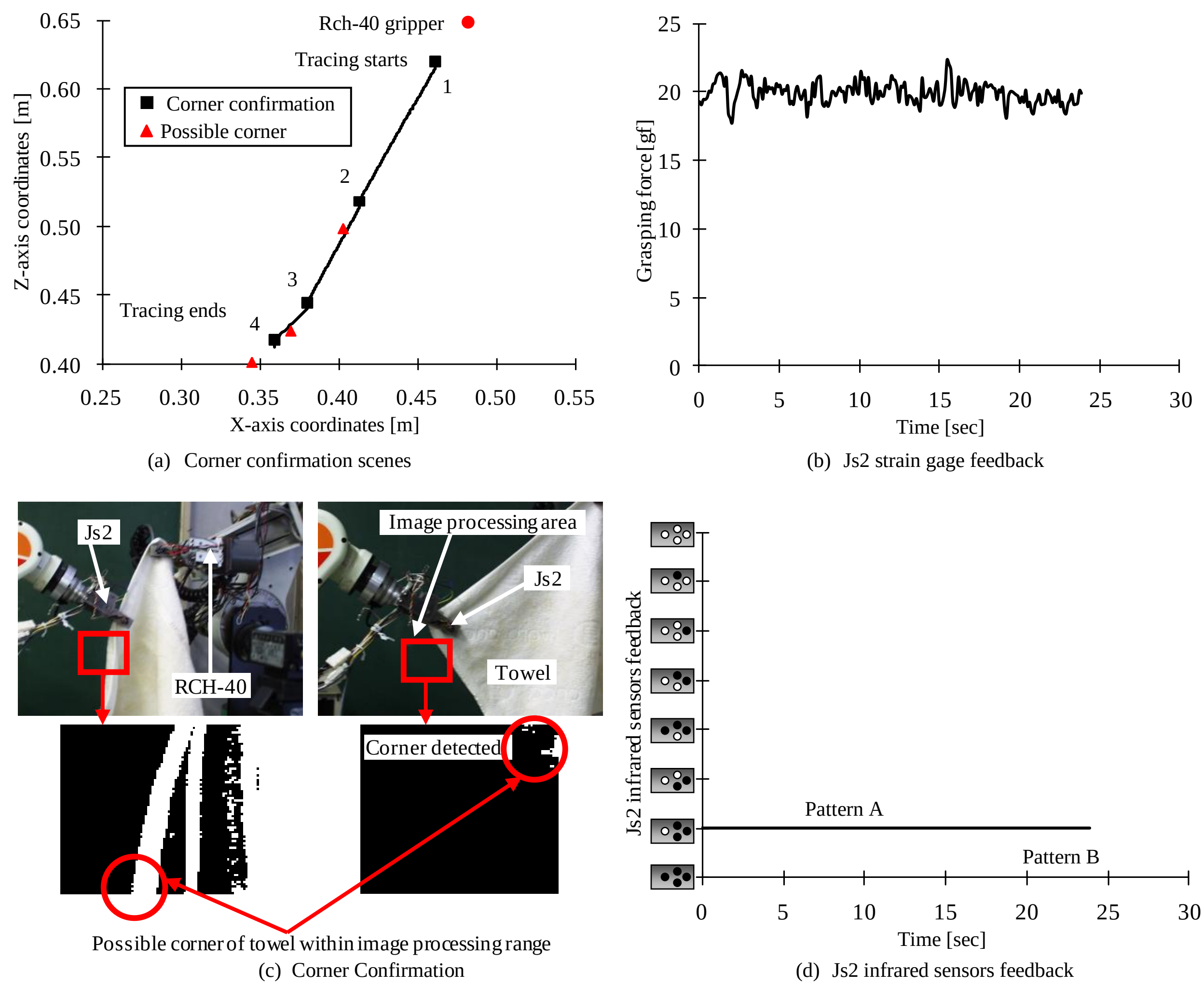

Figure 10. Real-time path planning tracing experimental data

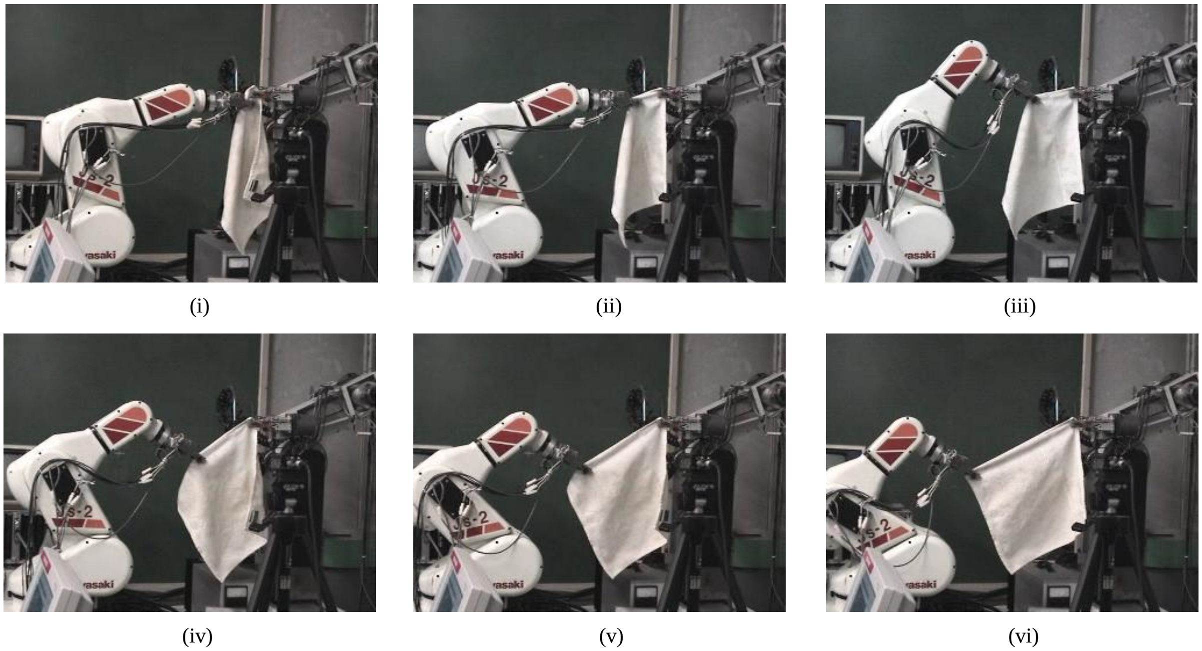

Figure 11. Scenes during edge tracing

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

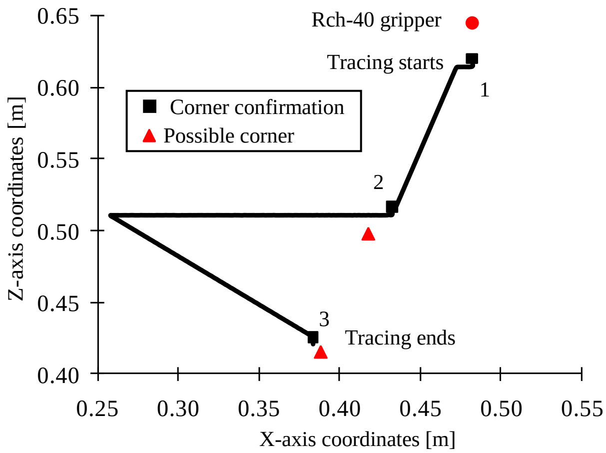

Figure 12: Js2 trajectory during real-time path-planning with target point set at (X_c+0.01, Y_c)

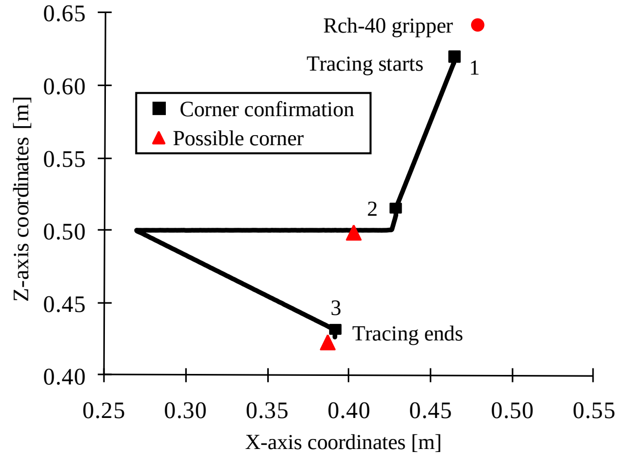

Figure 13: Js2 trajectory during real-time path-planning with target point set at (X_c+0.02, Y_c)

Table1. Data on performance of proposed tracing algorithm

Tracing method/setup	**Running time average** (|**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

Khairul Salleh Mohamed Sahari thanks Ministry of Science, Technology and Innovation (MOSTI), Malaysia for the Brain Gain Malaysia grant for Post-Doctorate. This work is supported by internal research grant from Kanazawa University, Japan and the Ministry of Higher Education of Malaysia under the project code: FRGS/ FASA1-2009/ TEKNOLOGI & KEJURUTERAAN/ UNITEN/ 9.

REFERENCES

[1] H. Toda, and G. Capi, “A High Resolution of Human Breath Gas Sensor and the Analysis of Hyperventilation for Rescue Robotics in Disaster Zones”, International Journal on Smart Sensing and Intelligent Systems, vol.3, no.2, pp. 292-303, 2010.

[2] N.G. Jabson, K.G.B. Leong, S.W. Licarte, G.M.S. Oblepias, E.M.J. Palomado, and E.P. Dadios, “The autonomous golf playing micro robot: with global vision and fuzzy logic controller”, International Journal on Smart Sensing and Intelligent Systems, vol.1, no.4, pp. 824-841, 2008.

[3] M. Nakazawa, “Handling of Flexible Object”, Journal of Robotics and Mechatronics, vol.10, no.3, pp.167-169, 1998.

[4] J. Brown, S. Sorkin, C. Bruyns, J.-C. Latombe, K. Montgomery, and M. Stephanides, “Real-time simulation of deformable objects: tools and application”, in Proc. of Conference on Computer Animation, pp. 228-258, 2001.

[5] J. Barbič, M. da Silva, and J. Popović, “Deformable Object Animation Using Reduced Optimal Control”, ACM Transactions on Graphics, vo. 28, no. 3 (SIGGRAPH 2009), 2009.

[6] Y. Kita, F. Saito, and N. Kita, “A deformable model driven visual method for handling clothes”, in Proc. of International Conference on Robotics and Automation, pp.3889–3895, 2004.

[7] A. Saxena, J. Driemeyer, and A. Ng, “Robotic grasping of novel objects using vision”, International Journal of Robotics Research, vol. 27, no.2, pp. 157–173, 2008.

[8] F. Osawa, H. Seki, and Y. Kamiya, “Clothes folding task by tool-using robot”, Journal of Robotics and Mechatronics, vol. 18, no. 5, pp. 618–625, 2006.

[9] M. Kaneko, and M. Kakikura, “Plannning strategy for putting away laundry –Isolating and unfolding task –”, in Proc. of the 4th IEEE International Symposium on Assembly and Task Planning, pp. 429-434, 2001.

[10] P. Gibbons, P. Culverhouse, and G. Bugmann, “ Visual identification of grasp locations on clothing for a personal robot”, in Towards Autonomous Robotic Systems (TAROS), pp. 78–81, 2009.

[11] D.J. Balkcom, and M.T. Mason, “Introducing robotic origami folding”, in Proc. of IEEE International Conference on Robotics and Automation, pp. 3245-3250, 2004.

[12] K. Salleh, H. Seki, Y. Kamiya, and M. Hikizu, “Tracing Manipulation in Clothes Spreading by Robot Arms”, Journal of Robotics and Mechatronics, vol. 18, no. 5, pp. 564-571, 2006.

[13] E. Ono, N. Kita, and S. Sakane, “Unfolding a folded using information of outline with vision and touch sensor”, Journal of the Robotics Society of Japan, vol. 15, no. 2, pp. 113-121, 1997.

[14] N. Fahantidis, K. Paraschidis, V. Petridis, Z. Doulgeri, L. Petrou, and G. Hasapis, “Robot Handling of Flat Textile Materials”, IEEE Robotics & Automation Magazine, vol. 4, no. 1, pp.34-41, 1997.