Proceedings of Taros'09, Londonderry, 31 Aug.-2 Sept. 2009, pp: 78-81.

Visual Identification of Grasp Locations on Clothing for a Personal Robot

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Abstract— **This paper describes a process for identifying possible grasping locations on a randomly positioned pile of clothes. For each pile, a robotic gripper is remote controlled to determine the possible grasp locations. These are highlighted on images captured from the robot's onboard camera. Grasping points are generally edges of clothes and rarely folds. A catalogue of visual features categorising grasping points is produced. The orientation of the grasp varies over the workspace reflecting the kinematics abilities of the robot. The relation between gripper orientation and visual feature orientation is analysed. A method is proposed for visually identifying feasible grasping points which reflect the robots ability.**

I. Introduction

The idea of robots helping in the home has existed since the original concept of a robot was conceived many years ago. Whilst inventions such as the washing machine, dishwasher and vacuum cleaner have helped to reduce the time and effort spent doing household chores a significant proportion of our lives are spent doing household jobs [1], [2]. A common theme between many of the most laborious household chores [3] is the ability to grasp and manipulate highly deformable objects such as clothing. If a robot is to become a useful household appliance [4]-[7] then it must be capable of completing challenging real world tasks such as cleaning, washing & ironing [8]. This premise also holds true for the service and manufacturing industry which still rely heavily on intensive human labour to perform fabric manipulation tasks.

Our main research interest is the design of a domestic robot which can perform a practical real world fabric manipulation task such as sorting clothes. In a previous paper [9] we reported on the observation of humans performing such tasks and proposed a conceptual model describing a sequence of cognitive processes involved in fabric sorting. The work presented in this paper aims at developing a more concrete model of the process for visual selection of grasping points. Given the complexity of image processing in the case of folded fabrics we decided to restrict as much as possible the visual search space by taking into account the kinematic properties of the robot arm and gripper. To that end we placed a robot in front of a series of random piles of clothes and for each of them we recorded the visual characteristics of reachable grasping points.

Manuscript received May 21, 2009. This work was supported in part by the Engineering and Physical Sciences Research Council (EPSRC) doctorial training account.

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II. Experimental Method

The robot used in the experiment is a commercially available Bioloid robot with a pair of custom made grippers and two web cameras on a pan and tilt system. The robot stands approximately 45 cm tall and has a total of 24 degrees of freedom. Each arm has 5 degrees of freedom, consisting of two degrees of freedom at the shoulder and a single degree at the elbow joint, wrist joint and gripper. The elbow and wrist joints are restricted to a rotation of 90° and the gripper can open to a maximum of 2 cm with a reach up to 4 cm and a width of 1 cm. The shoulder and elbow joints of both arms are controlled by moving a similar Bioloid connected robot via a wireless link. The shoulder joint had two degrees of freedom and the elbow joint one degree of freedom. A further two degrees of freedom were provided by the rotation of the wrist joint and the opening and closing of the gripper. These were controlled via a software interface along with the pan and tilt joints for the head.

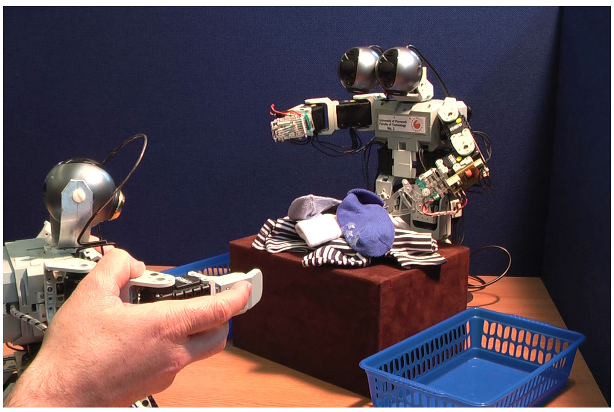

Fig. 1. Experimental setup for investigating grasping locations on an item of clothing from a pile of randomly positioned clothes. In the foreground a similar Bioloid robot is used to remotely control the other.

The pile of clothing consists of a range of small baby clothes with a variety of colours, textures and shapes. Between 4 - 7 clothing items were randomly position onto a 15cm tall surface in front of the robot. Either side of the surface is a small basket where items of clothing are placed during a separate sorting task. The full experimental setup is shown in Fig. 1.

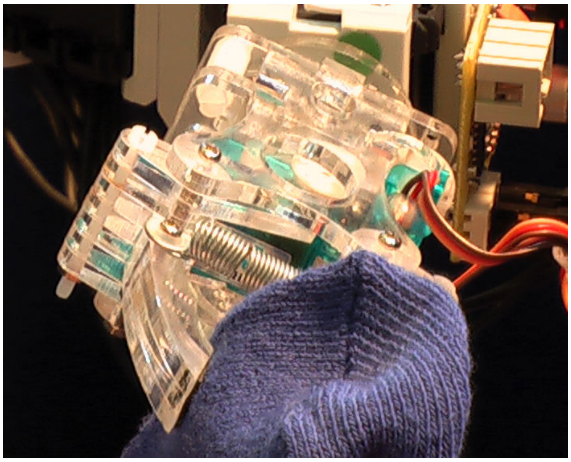

Fig. 2. Light weight gripper designed to produce a pinch grip for grasping the item of fabric clothing.

The light weight gripper was designed to produce a pinch grasp similar to a human pinch grasp created by using a single finger and thumb. Observations made in previous work [9] showed that the initial grasp was always made using a pinch grip. The gripper is opened using a small servo motor and then held closed by a spring. The friction between the point of contact of the gripper and the fabric is provided by a rubber strip fixed to the end of the gripper. This provided sufficient force to prevent the item of clothing from slipping during the experiment. Fig. 2 shows the gripper pinching an item of clothing during the experiment.

A remotely operated robot was used to control the robot. This enabled the instructor to easily explorer all the potential grasping locations guided by either looking directly at the experimental setup or by looking at the live pictures captured from the onboard cameras. The wrist joint was controlled via software interface by using a mouse on a scroll bar to alter the angle of rotation. A simple open or close button on the interface also enabled to gripper to be controlled. The operator noted all possible locations and orientations for grasping the clothing. The orientation included the angle of the grasp location, the angle of approach for the robot arm as well as the angle of rotation for the wrist joint. A possible grasp location was determined by the robot being capable of grasping the item of clothing at that location.

The cameras are both Logitech Pro5000 webcams which can capture images up to a resolution of 640 x 480 pixels and up to a rate of 30 frames per second. During the experiment a single image of the pile of clothes was captured from the left camera at a resolution of 640 x 480 pixels. All the possible grasping locations where the robot could successfully grasp an item of clothing were highlighted on the image by an ellipsoid, Fig. 3. The length of the ellipse reflects all the possible grasp points along a single orientation of a geometric feature on an item of clothing. To simplify the analysis only the central point of the ellipse was highlighted as the direction of approach of the robot hand. The angle of approach was highlighted on the image as a coloured arrow which intersects the line running the length of the ellipse to represent the orientation of the grasp line. The variation in angle from the perpendicular intersection was measured for each grasp.

Fig. 3 shows an image captured from the onboard camera with ellipses marking grasp regions. A green colour indicates grasping points for the left hand of the robot and a black colour is used for the right hand of the robot.

The gripper could be rotated through an angle of 0°-180°, although experience gained through experimentation showed that in reality the wrist was only rotated to either 0° or 90°. The gripper wrist orientation was therefore categorised as either a top/bottom motion similar to a human mouth or a sideways motion similar to a crab claw. This is reflected in Fig. 3 as a red arrow for a top/bottom grip and a blue arrow for a sideways grip.

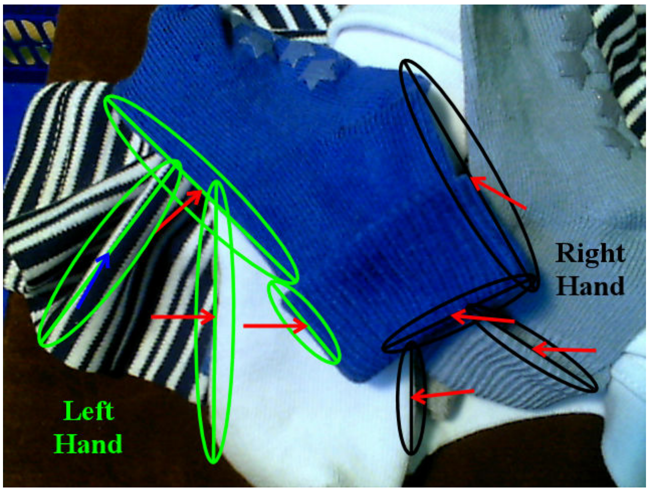

Fig. 3. Image captured of a pile of clothes from the robots onboard camera. Grasp regions and grasp orientation highlighted by an ellipse and a line. Green shows left hand grasp and black right hand grasp. The gripper orientation is shown by an arrow intersecting the centre of the grasp line. Red arrows show top/bottom grasps and blue arrows show sideways grasps.

The experiment was repeated for 10 different scenes each containing a random selection of clothes positioned randomly in a pile on the surface. The grasp locations and

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orientation data for each scene were recorded. The areas highlighted by ellipses were used to develop a catalogue of visual features. These were categorised into the visual properties of colour, texture, edges, ridges and depth discontinuity.

The visual features from two of the scenes were used as a training set for finding corresponding matches in the images captured from the other scenes. A 30x30 pixel square section was selected from the centre of the ellipsoid to match the size of the gripper. The filter was then rotated through 360° in 15° intervals and the best corresponding match for each scene recorded. This was done using a cross correlation algorithm by matching the intensity image of the filter against the intensity image from the scene. A total of 13 filters from two scenes were used for the training set and tested against the remaining 9 different scenes. The location of the best match for each filter in each different scene was compared against the highlighted ellipsoid regions for that scene to determine whether the selected point was at a graspable location for the robot. If the best match did not fall within a graspable region then it was subsequently evaluated by human eye to determine if it was at location which constituted a grasp point such as a fold or an edge. If the corresponding match was not at any graspable location then it was recorded as a fail.

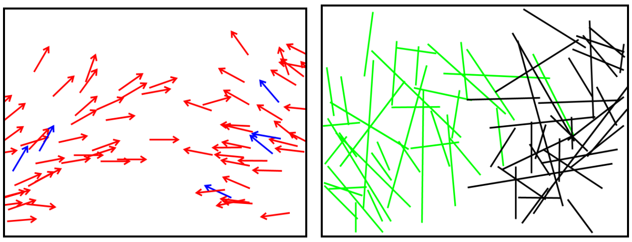
III. Results

The results from the analysis of the data can be split into three areas; the robot kinematics, the feature orientation at the grasp locations and the visual features at the grasp location.

Overall, there was a total of 75 grasp locations identified from 10 different randomly positioned piles of clothes. The left hand accounted for 52% of the grasp locations and the right hand 48%. This small bias towards the left hand is likely to be a result of using the image captured from the left-side onboard camera.

A. Kinematic Effects

The approach direction of the robot gripper and the orientation of the robots wrist reflect the kinematic properties of the robot arm. Potential grasping points positioned either closest or furthest from the centre of the robot could often not be reached due to the kinematics restrictions of the robot. One notable result was that the arms rarely crossed the medial line of the robot to reach a grasp location. This was partly due to the kinematics of the robot and also partly due to the nature of a pile of clothes. Towards the limit of the reach of the robot there is a reduction in the range of orientations possible for grasping. Also the item on the top of the pile often prevented the robot being able to reach other grasp locations on the opposite side of the pile to the robot arm. The nature of fabric in a layered pile means there are few protrusions offering suitable grasping points on the opposite side of a pile. The orientation of the wrist was predominantly top/bottom with sideways grasps only accounting for 8% of the overall grasps. Sideways grasp were used for folds or ridges in the vertical plane whereas top/bottom grasps were always used for edges and approached in the horizontal plane.



(a) (b)

Fig. 4. (a) Gripper direction (arrow direction) and wrist orientation (red top/bottom, blue sideways) for the left and right robot arm. (b) Feature orientation of grasp location on items of clothing in a randomly positioned pile (left hand is shown in black and the right hand is shown in green).

B. Feature Orientations

The ideal direction for the gripper to approach a graspable edge would be at a right angle. In practice an edge can be grasped from a range of non-perpendicular orientations. Fig. 3(b) shows the orientation and the length of the features edges corresponding to the gripper direction in Fig. 3(a). The deviation of the gripper angle from the feature angle was measured for each grasp, as shown in Fig. 4. Half of all grasps fell within a range of ± 30°, two thirds of all the grasps fell within a range of ± 45°, and 80% of within a range of ± 60°. The length of a feature edge at a grasp location varied from a minimum of 20 mm to a maximum of 120 mm, with the average length being around 50 mm. The width of the robot gripper is 10 mm.

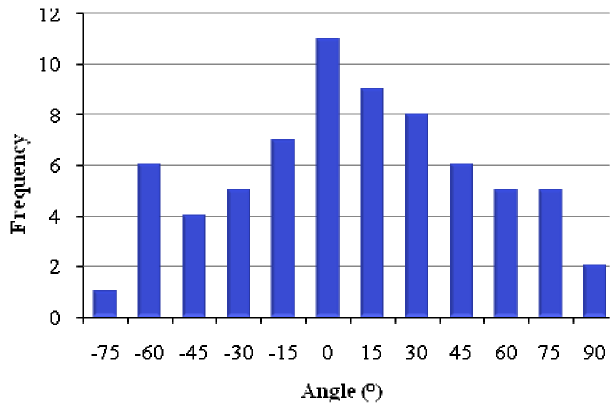
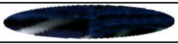


Fig. 4. Histogram of frequency of range of angles between ideal angle of gripper orientation and actual angle.

This result allows a restriction of the range of orientations to be searched by image processing algorithms for each point in the image.

Table. 1. Samples of visual features of grasping points on items of clothing with changing visual properties defining a graspable edge.

Sample of Visual Features	Intensity	Colour	Texture	Depth
	✓	✓		✓
			✓	✓
	✓	✓		✓
			✓	✓
	✓	✓		✓
	✓	✓	✓	✓
	✓	✓		✓
			✓	✓
				✓
	✓	✓	✓	✓

C. *Visual Properties of Grasp Points*

The ellipse used to identify the location and orientation for grasping points provides information about visual properties at each point. Table 1 suggests that either a monocular vision system or a depth vision system would be suitable for identify grasping points. A monocular system will require the detection of edges defined by complex combinations of visual properties such as; colour, texture and intensity. Alternatively stereo vision (depth) may provide a simpler solution to the detection of suitable edges.

One method of using a monocular vision system to detect potential grasp locations was explored by creating a filter from a sample of visual features. Overall 13 filters in the training set taken from two scenes were matched against features in the other 9 scenes. A total of 117 matches were produced resulting in 27% corresponding to a graspable point reachable by the robot. A further 41% of matches were considered to be at a location which could be grasped if the restrictions of the robots kinematics were removed. And 32% failed to match an area which could be grasped. The results for each filter in the training set varied from no graspable matches being found to over 70% of matches being located in a graspable region for the robot. Generally the filters with a larger change in contrast performed far better than filters with a small change in contrast.

IV. Conclusion

The visual properties of fabric grasping points reachable by a small personal robot were investigated. The robots arms were remotely controlled via an identical robot to find actual grasp locations on 10 different piles of clothing. The position and orientation of each grasp was highlighted on an image captured by the robots onboard camera. The results show that the accessible grasping points are restricted by the kinematic range of the robot and by the physical properties of piles of clothes. These restrictions also affect the visual search space of suitable grasp locations and reduce the image processing problem. The experiment has provided a catalogue of visual properties characterising potential grasp locations. Visual features with a larger change in contrast performed better than features with smaller changes in contrast when identifying potential grasp locations in other images. Improved detection algorithms now need developing.

A notable characteristic of the proposed approach is the recognition that the visual processing task is constrained by the kinematic abilities of the robot.

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