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Planning Strategy for Putting away Laundry – Isolating and Unfolding Task –

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Abstract

Study on Service Robot for Housekeeping which deals with the laundry, such as pants, a shirt and a towel, is promoted. A robot has to treat a variety of "nonsolid " objects, as well as solid objects, in a house. In order to improve the technology for handling a nonsolid object, we study making a robot put away the laundry. The task of putting away laundry is composed of the isolating task, the unfolding task and the folding task. These tasks include some subtasks, segmenting an image of a washed mass into some regions, taking out clothes from a washed mass, rehandling clothes, classifying into each clothes' type, recognizing from of clothes, folding clothes and putting clothes on a specified place. This paper proposes the planning strategy for the isolating task and unfolding task.

1 Introduction

Study on the Housekeeping robot is promoted in our laboratory. The robot has some special problems to realize it, for example, the robot must treat various objects in a house. Especially, the robot has to handle a "nonsolid" object. A variety of research on handling a nonsolid object[1] has been conducted so far. Kabaya et al. manufactured the hand having a rotational mechanism for grasping a sheet laid flat on a workbench and succeeded in realizing a stable grasping action[2]. Osawa et al. added a function corresponding to human nail to the above-cited hand[2] and succeeded in grasping clothes more accurately and stably[3]. When clothes on a workbench are folded, it is frequent that a hemline of overlapping section cannot be detected only with visual information. Ono et al. detected the position by searching a folded section with cooperative sensing with a vision and touch sensor[4]. In case of planning a task for handling a nonsolid object, it is a problem how and to what degree deformation is considered. If a model calculated strictly shape is used, computation grows so excessive, therefore, it may be impossible to control in practical processing time. Wada et al. studied the shaping task of knit clothes and proposed a control method that a model with error of an object can be convergent to a desired value[5]. These research treat grasping a nonsolid object, recognizing its local state such as a hemline of overlapping section and deforming it locally. However, recognizing entire state of a nonsolid object and planning strategy for deforming it wholly have not been studied.

Our study focuses on how to recognize and handle a nonsolid object such as clothes and we are trying to solve these problems through development of a robot which can put away clothes, i.e. the robot takes out one clothes from a washed mass at the first step, then unfold it with two manipulators, and finally fold it. In this paper, how to isolate one clothes from a washed mass, classify it into a shirt, pants and a towel, and recognize its form are described.

2 Flow of Robot Task

The flow of the whole task for putting away laundry is shown in Fig.1. The task is composed of three parts: isolating, unfolding and folding.

In the isolating task, one clothes is isolated from a washed mass. Firstly, a top view image of the washed mass is divided into some regions with color information of the image. The largest region is chosen as a grasping point and the clothes is hung up with one manipulator.

In the unfolding task, at first, two grasping points are decided on unfolded clothes and then the robot holds these points with its two manipulators. This task, called the rehandling task which is a subtask in the unfolding and folding task, is repeated until the clothes are properly spread to facilitate the classification of the clothes. After the clothes are expanded properly, the classifying task is performed under the clothes hung up and is inferred into three classes, a shirt, pants and a towel. Every time the rehandling task is executed, recognizing form of the clothes is conducted to obtain the current grasping points and the current form of the clothes beforehand. This task is performed to derive how to deform the current form of the clothes to the next planned form according to the unfolding and folding process. And then, the robot puts the clothes on the working table and unfolds it. This process is called the shaping task.

In the folding task, firstly, the clothes are roughly unfolded, and then local deformation, e.g., wrinkle, in the clothes is smoothed. Finally, the clothes are folded and put on the specified place.

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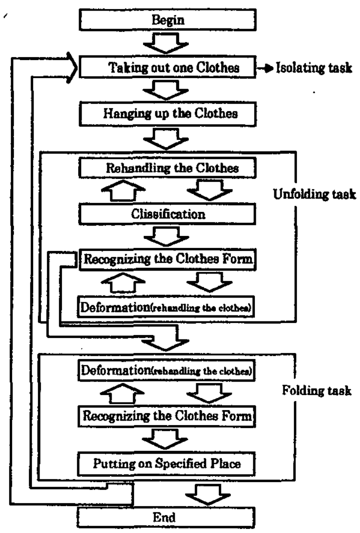


Fig.1 Flow of task

3 Isolating Task

In this task, it is attempted to isolate one clothes from a washed mass. The process is shown in Fig.2.

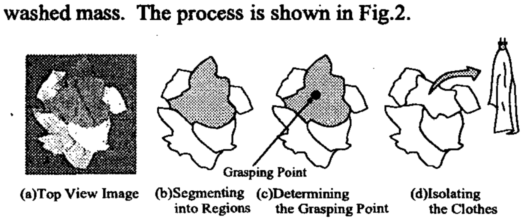


Fig.2 Isolating task

Each process is as follow: (a)A top of view image of a washed mass is gained. (b)The image of the washed mass is segmented into the independent region of each clothes with color information. (c)The area of each region is measured. The largest region is determined as the region including grasping point, and then the grasping point is determined. (d)The robot isolates one clothes from the washed mass with the hand, that has been developed in our laboratory[1].

In order to segment the image of a washed mass into regions of each clothes, the region segmentation of the image on the washed mass is conducted with color information on the image, which is three color components(red, green and blue).

Initially, the robot examines whether the color of the washed mass is solid or not in order to change the procedure of the region segmentation by the result. In case of nonsolid color, it is necessary to be carried out the region segmentation of the washed mass. The process of the region segmentation is indicated the following.

(1)Three histograms(R, G, B) of the region of the washed mass is derived from the color images and then the most outstanding peak of Red_{peak}, $Green_{peak}$ or $Blue_{peak}$ is obtained from them as the value of the threshold for extracting a region. (2)The pixels corresponding to the peak are extracted from that color component image which is binarized by the color having the most outstanding peak. (3)Then, the region, which consists of connection of those pixels, are detected. (4)The above process is repeatedly applied for the connected region gained in process (3) to find out much smaller a connected region, and also for other remaining regions. In this case, the color component which is not used in process (1)-(3) is applied. The process of the region segmentation ends up if any region cannot be divided into much smaller region.

The largest region in the extracted region is decided as the grasping region. If all the region are smaller than the minimum grasping region, the region of the whole washed mass is regarded as the grasping region.

Next, in case of solid color, variation of pixel value in color space is mild, therefore, each region of the washed mass is not detected clearly unlike the case of nonsolid. In this case, two kinds of shadows which appear on the washed mass by multidirectional lighting is used, one represents discontinuity and another shows roughness of the surface, since it is comparably easy to obtain these information. Therefore, the grasping region is determined with edge information which is detected by binarization. Assuming that the detected edge is the boundaries of clothes, the region enclosing these edges is regarded as the grasping region. If the region is smaller than the minimum grasping region , the region of the whole washed mass is considered as the grasping region like the case of nonsolid.

4 Unfolding Task

The unfolding task is the preparation process for folding clothes. Since it is difficult to unfold clothes entirely at one try, clothes is unfolded roughly in the first step. Then, clothes is unfolded by smoothing local deformation. Thus, clothes is folded step by step.

The flow of the unfolding task, which has three subtasks, is shown in Fig.3. The initial state of the clothes in the unfolding task is the clothes hung-up state with one manipulator(Fig.3(a)). At first, two points on hemlines of the clothes are discovered as new grasping points for rehandling. As changing of the grasping point is performed several times(Fig.3(b)), the clothes is expanded. Then, the clothes is put on the working table so that the clothes is not crumpled(Fig.3(d)).

In the first rehandling subtask as the first step in the unfolding task, it is necessary to find out two grasping points under the clothes hung-up state. After that, the clothes is hung-up by grasping them with two manipulators. To prevent from crumpling the clothes, two grasping points are selected so that they are not set closely on the same hemline, except for setting on each end point of the same hemline.

In order to grasp one hemline on the cloth, how to detect hemlines is presented as follows. The information of the clothes, which is the shadow appearing on the clothes and the shape of outline of the clothes under the clothes hung-up state, is applied for detecting hemlines on the clothes. The reason why the information is used is the following(See Fig.4). The shape of edge of the clothes' hemlines frequently makes a convex shape by the effect of gravity(the edge line made by the grasping point, point A and point B in Fig.4,right). Therefore, if the region of shadow is detected on the convex shape of the clothes' outline, this indicates existence of hemline.

The second rehandling subtask is performed as same as the first rehandling process. In this task, the hemline grasped in the first rehandling process seldom makes a convex shape, since the clothes is sagged down by its weight. Therefore, the possibility that a shadow region exists close to the grasped hemline is reduced greatly, thus, the condition, as mentioned above, that two grasping points may not be set on the same hemline, can be satisfied.

In case that a hemline can not be detected by using information of a shadow region, the lowest part of the clothes is defined as a grasping point as shown in Fig.5.

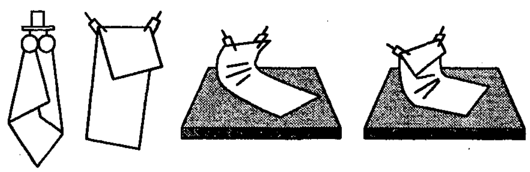


Fig.3 Three subtasks of the unfolding task Intial state : (a)hung-up state; subtasks: (b)rehandling, (c)putting on the working table, and (d)shaping

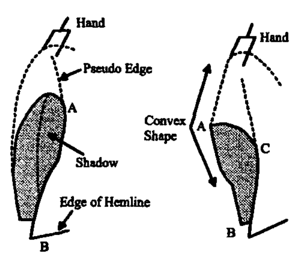


Fig.4 Relation between hemline and shadow

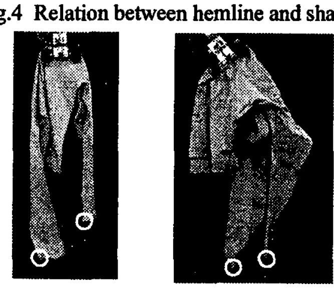


Fig.5 The bottom point for the grasping point

5 Classifying Task

The classifying task is a part of the unfolding task and is conducted under the clothes hung-up state at two grasping points on the hemline after the rehandling task. It is easy to obtain a general feature of clothes, since clothes are spread out and feature of clothes is exposed under this condition. In this paper, class is a kind of clothes, a shirt, pants and a towel.

The flow of the classifying task is shown in Fig.6. At first, classification by type is performed. On the other hand, shapes of object are represented with convex closures and convex absences beforehand and classified into three types with the state of the convex absence(See Fig.7). Lastly, quantities of feature decided by each type are calculated and classifying is done with these values.

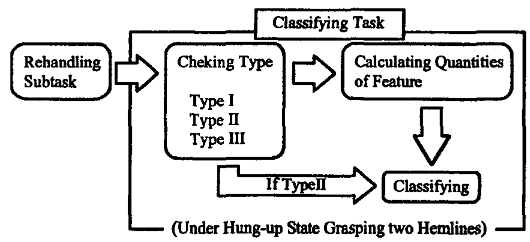


Fig.6 Flow of the classifying task

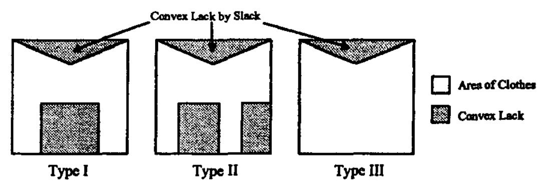


Fig.7 Higher models of hung-up clothes

5.1 Model Setting

In general, regarding a deformable object having 2D spread, its hanging shape easily changes by influence of the grasping point, so that the number of the hanging shape exists as many as the number of grasping points which can be set on the object. On the other hand, if the grasping point shifts to a close point, the general feature does not change largely. Therefore, it is possible to gain a set of grasping points producing similar general features, in other word, the neighborhood, and the hanging shape of clothes, which is grasped at one point within a neighborhood, can be defined as the general feature regarding the neighborhood.

In order to obtain characteristics shapes under the condition of grasping at two points in the hemline, shifting the grasping point little by little, an experiment is conducted and the characteristics shapes are registered as models of each class, a shirt, pants and a towel. These models are used for classifying. As a result, 8 shapes for a shirt, 3shapes for pants and 7shapes for a towel are obtained as the models of the hanging shape as shown in Fig.8.

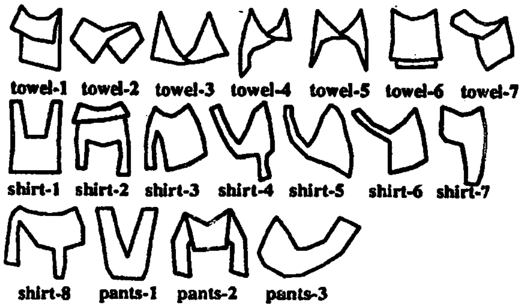


Fig.8 Models of hung-up clothes

Meanwhile, the three superior models are defined to determine the quantities of feature concerning the hanging shapes. These models are represented with convex closures and convex absences and classified according to the number of the convex absence adjacent to protruding regions(Fig.9). The case that one convex absence is detected from an image is defined as Type I, two convex absences Type II and no convex absence Type III. The quantities of feature for each model in Fig.7 are defined by using a ratio of a length on each section and a ratio of area in Fig.10. The quantities of feature for Type I are shown in Table 1 as an example and the definition of each symbol in Table 1 is shown in Fig.10. These quantities of feature are decided empirically with many experiments. However, obtaining the quantities of feature regarding Type II is not conducted, since Type II may be generated only for the case of a shirt, in case that the hanging shape is discriminated to be Type II, it can be recognized as a shirt.

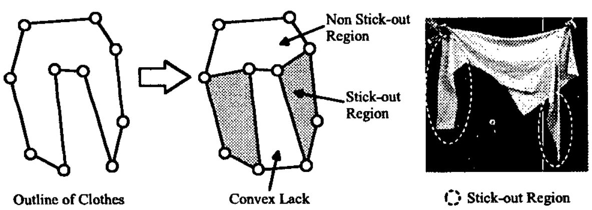
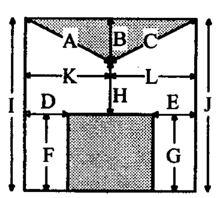


Fig.9 Stick-out and non stick-out region



Type I

Fig.10 Measuring part of Type I

Table.1 Quantities of feature for Type I

Quantities of Feature	Definition
f1	$\frac{\text{Area of Stick-out Region}}{\text{Area of Non Stick-out Region}} \times 100$
f2	$\frac{K+L}{H}$
f3	$\frac{A}{H}$ $\frac{C}{H}$
f4	$\frac{K}{L}$
f5	$\frac{D}{F}$ $\frac{D}{E}$
f6	State of Convex Lack
f7	the Number of Detected Stick-out Region

5.2 Type Classifying Process

The contour of an object is represented with convex closures and convex absences and classifying is performed according to the number of the convex absence adjacent to protruding regions. Due to Fig.7, the number of the convex absence is at maximum 2(except for convex absence caused by slack). However, depending on an object shape, 3 or more convex absences may appear. If the quantities of feature of these convex absences are less than a threshold value, they are deleted. An area of a triangle which is composed of two lower end points of a convex absence and one point of the bottom of a protruding region is used as a quantity of feature for the convex absence(Fig.11). One convex absence is assumed to be adjacent to two protruding regions. In Fig.11(a), the points b1 and b2 are the lower end points of the convex absence and the points t1 and t2 are respectively the bottom points of the protruding region. In this example, the area of two triangles △b1t1b2 and △b1t2b2 is used for the quantities of feature of the convex absence. If one or two of these two triangles are over the threshold value regarding area, they are identified as the convex absence adjacent to the protruding region. In case that neither triangle is over the threshold value, the convex absence is deleted. The process of selecting the bottom point is changed(Fig.11(b), (c)), based on smoothness of the contour constructing the convex absence. If there is irregularity in the contour of the convex absence as shown in Fig.11(b), searching starts from respective lower end point(Fig11(b), p1, p8) and the point that the area of the triangle is the maximum is defined as the bottom point(Fig11(b), p4, p6). In case that the contour is smooth(Fig.11(c)), the point that the area of the maximum is selected as the bottom point(Fig.11(c), p4).

Next, the process for recognition of a protruding region is presented below. The way of detecting a protruding region is to discover a region constructed by connecting the bottom points and one point on the contour.

(1)All the point sequences of the convex absence including the bottom points are deleted from the point sequences on the contour. In Fig.11(a), t1 and t2, are the bottom points, so all the point sequences of the convex absence including these two points are deleted.

(2)The nearest point to the bottom point is chosen from the remaining point sequence after process (1). In Fig.11(a), t3(the nearest point from t1) and t4(the nearest point from t2) are chosen.
(3)The clothes is divided by connecting the bottom points and the points selected in process (2).
(4)The region containing the bottom points and the lower end points of the convex absence among the divided region is regarded as the protruding region.

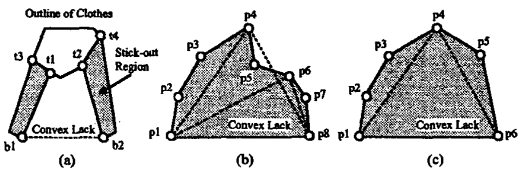


Fig.11 Feature quantities of convex lack

5.3 Classifying Process

The quantities of feature defined by models of each type are calculated and the classifying task is performed. If the clothes is recognized as Type II, it is classified into a shirt. The classifying process for Type I are shown in Fig.12 as an example. The threshold values in Fig.12 are obtained from the shape to make models. The threshold values are set so that the same model is selected against the shape generated by grasping at the neighborhood of a point.

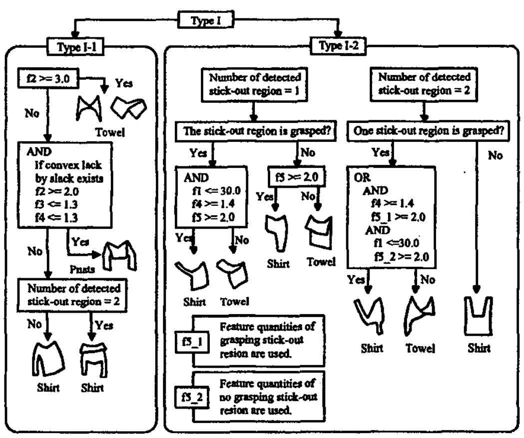


Fig.12 Flow of classifying clothes for Type I

6. Recognizing Form of Clothes

In case that a robot deforms clothes according to the unfolding and folding task, the robot need to recognize the form and the grasping point of the clothes, in order to plan a next action. At first, before the recognizing task is conducted, it is assumed that the aspect model of clothes is already registered in a robot. The aspect model is the aspect of clothes appearing under the condition that clothes is grasped at two points and hung up. And then, recognizing form of clothes is performed by comparing the aspect model with quantities of feature obtained from an image.

6.1 Aspect Model

As mentioned above, the aspect model is made by collecting the aspect of clothes grasped at two points and hung up. However, a great number of the aspect model must be prepared, because clothes generate innumerable forms on account of a deformable object. It is unavailable, therefore, it is necessary to reduce the number of the aspect model.

In order to decrease the number of the aspect model, the following fact and condition are applied. At first, as mentioned in section 5.1 above, if the grasping point shifts to a close point, the general aspect does not change largely. Therefore, it is possible to acquire only the minimum characteristics aspect model by grasping the points generating typical form of the hanging clothes. For instance, the grasping points of a shirt are shown in Fig.13. On the other hand, in case that a robot grasps two points and hang up clothes, slack and wrinkles generally occur in arbitrary direction and position by gravity. These indefinite factors are disadvantage for recognizing form of clothes. Therefore, in order to reduce these indefinite factors on clothes as many as possible, a robot tightens between the two grasping points. In addition, this condition facilitates to detect features, which are a sleeve, a collar, a button and so on, since more features are exposed. The examples for the aspect model of a shirt are shown in Fig.14.

Each aspect model is grouped by the position of features on an image and the sort of features(a sleeve, a collar, a button and so on) appearing on the hanging clothes. It is available for reducing the time for matching a model and error of recognition.

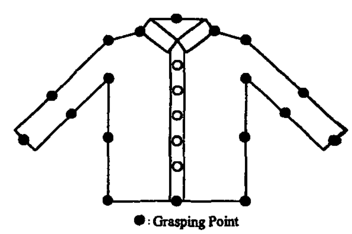


Fig.13 Grasping point for typical shape

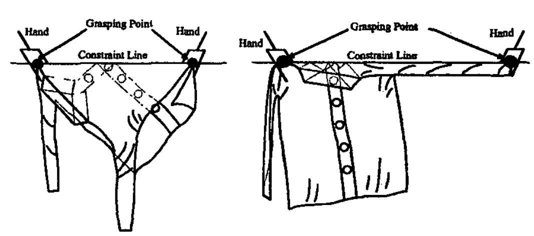


Fig.14 Example for the aspect model

6.2 Constructing Aspect Model

The aspect model is constructed with the physically based model clothes in virtual space. At first, the virtual clothes hung-up state is generated by grasping two points of the grasping points shown in Fig.13. And then, a virtual binarized image is obtained by lighting the virtual clothes like the lighting system in an experiment. This task is performed regarding all combinations of two points in Fig.13. Lastly, the quantities of feature of the model used for comparison with the quantities of feature from an image are detected.

Some researches on the physically based model of clothes are already performed in the field of CG(Computer Graphics) and CAD(Computer Aided Design) for the apparel industry[6]. In our research, these models are used to obtain the aspect model. However, these models are not strict, for example, expressing wrinkles and slack is difficult, since the model's target is that the model can behave like clothes. On the other hand, the important information for the unfolding and the folding task is the general shape of clothes, not local information, which is winkles and slack. In addition, if recognition of a grasping point has error, flexibility of clothes can absorb the error. Therefore, there is no problem with respect to using the model as mentioned above. However, matching the aspect model to features from an image needs to have flexibility.

7 Conclusion

The planning strategy for putting away laundry, which includes the isolating task, the unfolding task and the folding task, is described. Each task also consists of some subtasks. Especially, segmenting region of a washed mass, taking out one clothes, rehandling clothes, classifying into clothes' type and recognizing form of clothes is examined as subtasks in this paper. Results are described below.

(1) Region of a washed mass was divided into each clothes with color information on the image of the washed mass and one manipulator could take out one clothes from the washed mass by grasping the largest region.

(2) Rehandling aims at simplifying shape of clothes formed by grasping two points on the hemline of clothes in order to facilitate to classify a kind of clothes, and the grasping point could be detected by using convex sections and shadow sections generated in their vicinity.

(3) In classifying task, the shape of clothes under the hemline grasped 2 points was obtained, the quantities of features were calculated, and clothes were discriminated among a shirt, pants and a towel. In general, shape of hung-up a nonsolid object differs according to the position and the number of grasping point. When the number of grasping point is constant, if the grasping point is moved within a range, a general shape of clothes does not differ. Therefore, a grasping point set which generates similar general shape under clothes hung-up can be found. According to this fact, images of hanging clothes were acquired as general shapes, changing grasping points. As a result, 18 shapes(8 shapes for a shirt, 3 shapes for pants and 7 shapes for a towel) were generated as general shapes of hanging clothes.

(4) In order to prepare 3 kinds of superior models, 18 shapes obtained as models were classified by using the approximate representation having convex closure and convex absence. The quantities of features of the three superior models is defined to discriminate among 18 shapes.

(5) Threshold values were set based on the quantities of features acquired by the pre-experiment conducted under the clothes hung-up, and the experiment for classifying clothes was conducted. As a result, classification succeeded about 90%.

The concept of recognizing form of clothes with the aspect model is presented. The research on this task is currently promoted.

The next goals is

(1) to construct the aspect model and the physically based model of clothes for making the aspect model and establish the way of matching the aspect model to an image of clothes.

(2) to unfold the folded parts of clothes to the full extent and stretch the locally deformed parts.

Acknowledgements

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