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An Adaptive Welding System for Corner Joints Which Applies Joint Recognition by Deformable Template Matching

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ABSTRACT

This paper presents an application of a flexible model-based template matching algorithm named "deformable template matching." The template which models the shape of objects consists of some nodal points and segments that connect the nodal points sequentially. The template holds information about the known deformation of the object's shape, and it makes the shape recognition flexible. The matching is done by the energy minimization method basis, and it makes the recognition robust. This paper also shows an adaptive welding system which applies the algorithm.

I. INTRODUCTION

Recently, a lot of industrial robots are applied to welding work. They have greatly contributed to the stability of the welding quality, the cost reduction and the elimination of dangerous work. Most of the welding robots are teaching playback type. For such robots, it is difficult to compensate the difference between the programmed path and the actual seam position caused by the variation of parts and the misalignment of the parts setting. The lack of the compensation of the position error deteriorates the welding quality. Especially, the welding quality of corner joints composed of sheet metals are greatly influenced by the above-mentioned problem. The robot programming and the maintenance of programs for playback robots are difficult because the high-precision programming requires a lot of teaching points.

To solve the above-mentioned problems, some vision systems for adaptive welding have been applied. "Adaptive welding" can be defined as "an welding system that is able to properly adjust the welding path and the welding current by measuring the actual dimension and position of welded parts with a sensor mounted on the robot." Moreover, to reduce the tact time, the welding and the measurement have to be done at the same time. Therefore, the adaptive welding with a vision requires a fast and robust shape recognition algorithm.

This paper presents a fast and robust shape recognition algorithm for images acquired by a laser light-sectional sensor mounted on the robot hand, which recognizes 3-dimensional shape of the seam. This paper also shows an adaptive welding system which achieves the high-quality welding of corner joint that does not need any finish work by human workers.

II. SYSTEM OVERVIEW

Fig.1 shows the overview of the welding system. A laser light-sectional sensor is mounted on the hand of a 6-axis robot. It measures cross-sectional profile of welded objects. The sensor has high immunity against the arc light to measure objects during the welding. Fig.2 shows an example of a corner joint. Fig.3 illustrates the cross-sectional view of a corner joint. Fig.4(a)-Fig.4(d) show the various type of images acquired by the sensor. In these images, the vertical axis is the height of the measured object, and the horizontal axis is the direction of the scan. One image has 256 measured points, and each point holds 16-bit position data for each axis. Cross-sectional images acquired by the sensor are transferred to a 68030 CPU board in the controller, and they are analyzed by the "Deformable Template Matching" algorithm (described in the later chapter). After the tracking position, gap and mismatch shown in Fig.3 are measured by the algorithm. Using these data, the robot trajectory and the welding current are modified to achieve the adaptive welding. The welding path is optimized by the control of the robot trajectory. The metal melting is also optimized by the control of the welding current and the control of the torch position. By these control, the high-quality welding is achieved. The system also has to automatically find the Arc Start Point (ASP) and the End Of Seam (EOS).

The analysis of a image has to be done within 100msec because the robot corrects its trajectory at each 128msec. The accuracy of the tracking position has to be 0.1mm or less because the error of the torch position from its optimal position has to be less than 0.2-0.3mm. The accuracy of the gap and mismatch measurement also has to be within 0.1mm to control the welding current properly.

For the ASP/EOS capture, the shape recognition algorithm has to be able to distinguish the shape of the seam from the shape of the other part.

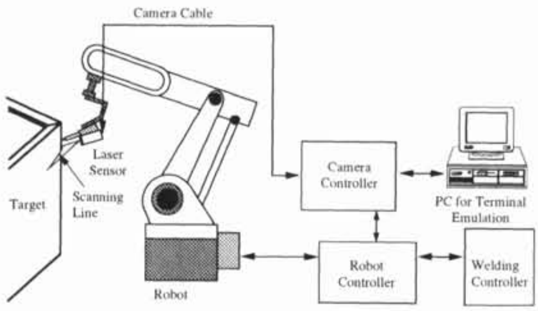


Fig.1 System Overview

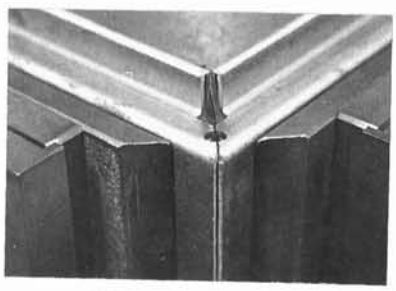


Fig.2 Corner Joint

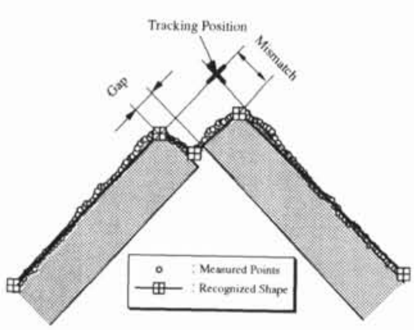


Fig.3 Cross-Sectional View

III. IMAGE PROCESSING

Images of corner joints have much variance on their shapes as shown in Fig.4(a)-(c) because of the variance of dimensions of gap and mismatch. Moreover, as shown in Fig.4(d), some images have discontinuous parts caused by a hole close to the seam or a small metal fragment on the metal surface. Conventionally, there are two algorithms for the analysis of light-sectional images. One is based on the local change of the depth; for example, differential calculus or K-curvature. However, these algorithms are sensitive to the local characteristics as seen in Fig.4(d) and are not robust. The other is the template matching algorithm that uses a template sampled from typical images. Though this algorithm is simple, but it will be time-consuming because it requires a lot of templates to recognize deformed shapes.

To solve the above-mentioned problems, a flexible model-based algorithm named "Deformable Template Matching" algorithm was applied. The deformable template matching has an advantage that it can recognize shapes even if it has a certain variance. The deformable template matching can be defined as "An algorithm that recognizes shapes by minimizing the difference between the observed shape of objects and a model of the object. The model contains some *a-priori* knowledge of the object to make the recognition flexible." In our application, the deformation of the welded parts is known. The method presented in this paper uses this information as *a-priori* knowledge. Concretely, the template used in the algorithm is a model of the objective shape, and it also holds the information about the deformation of the shape. Because of it, the template is flexible against the shape deformation. Therefore, the matching process does not need the time-consuming simulated annealing to deform the template or plural templates for various shapes. Detailed method is described below.

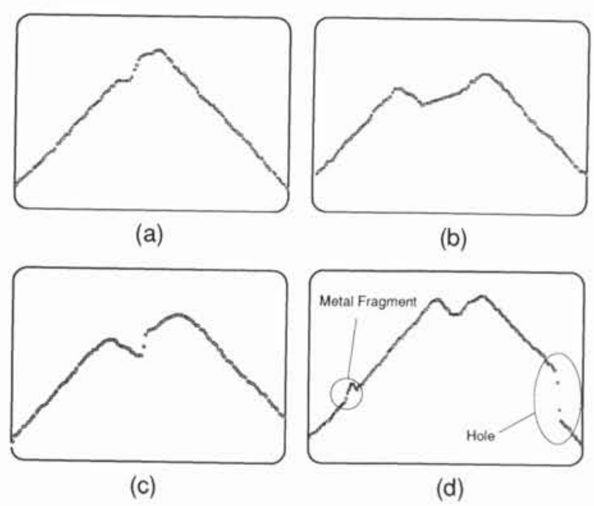


Fig.4 Images Acquired by the Sensor

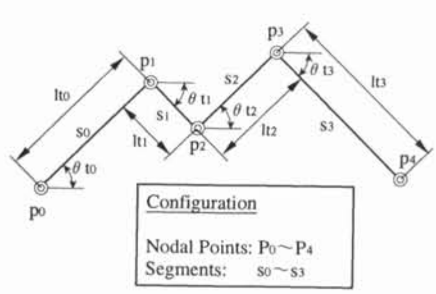


Fig.5 Template

· Deformable Template Matching

Fig.5 shows the template used in our algorithm. The "deformable template" is composed of 5 nodal points that makes 4 line segments by connecting neighboring nodal points. It models the contour of corner joints ("M" shape). For each segment of the template, a predetermined tolerance is given to its length and angle as the *a-priori* knowledge.

Tolerance for the length: lt_k

$$lmin_k < lt_k < lmax_k \quad (k=0,1,2,3)$$

Tolerance for the length: θt_k

$$\theta min_k < \theta t_k < \theta max_k \quad (k=0,1,2,3)$$

The tolerances indicate the allowed deformation of the template, and they make the template flexible. By matching this template to images, the shapes of the corner joints are recognized. The matching is done by deforming the original template to all possible shapes and by selecting the best shape that gives minimum "total deformation quantity." The deformation of the template is done by selecting a set of 5 points from the image and attaching the 5 nodal points of the original template to the selected 5 points. As the matter of course, the number of the possible shapes increases in accordance with the number of points contained in a image. To solve this problem, the point array contained in an original images are approximated to polygonal lines to decrease the number of points.

The "total deformation quantity" is the weighted summation of potential deformation quantity, length deformation quantity, and angle deformation quantity (See Fig.6).

$$E_{total} = W_p \times E_p + W_l \times E_l + W_\theta \times E_\theta$$

E_p: Potential deformation quantity

E_l: Length deformation Quantity

E_θ: Angle deformation quantity

W_p, W_l, W_θ: Weight for each factor

The potential deformation quantity is defined as the mean distance from points in the image to the segments of the deformed template. This deformation quantity evaluates the line-fitness of the point array in the image.

$$E_p = \frac{\sum_{j=0}^{n-1} (\varepsilon_j)}{n}$$

n: Number of data

The length deformation quantity is the summation of the differences between each segment length of the deformed template and the corresponding segment length of the original template.

$$E_l = \sum_{k=0}^{3} Dl_k$$

$$Dl_k = l_k - lmax_k, \quad l_k > lmax_k$$
$$Dl_k = 0, \quad lmin_k < l_k < lmax_k$$
$$Dl_k = lmin_k - l_k, \quad l_k < lmin_k$$
$$(k=0,1,2,3)$$

In the same manner, the angle deformation quantity is derived from the summation of the differences between each segment angle of the deformed template and the corresponding segment angle of the original template.

$$E_\theta = \sum_{k=0}^{3} (D\theta_k \times l_k)$$

$$D\theta_k = \theta_k - \theta max_k, \quad \theta_k > \theta max_k$$
$$D\theta_k = 0, \quad \theta min_k < \theta_k < \theta max_k$$
$$D\theta_k = \theta min_k - \theta_k, \quad \theta_k < \theta min_k$$
$$(k=0,1,2,3)$$

The length deformation quantity and the angle deformation quantity are to evaluate the difference between the actual shape and the shape registered in the template.

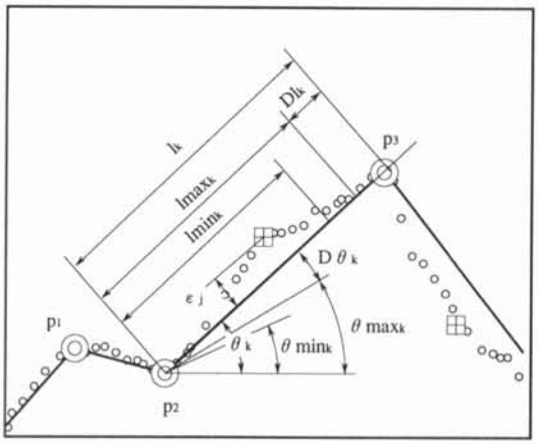


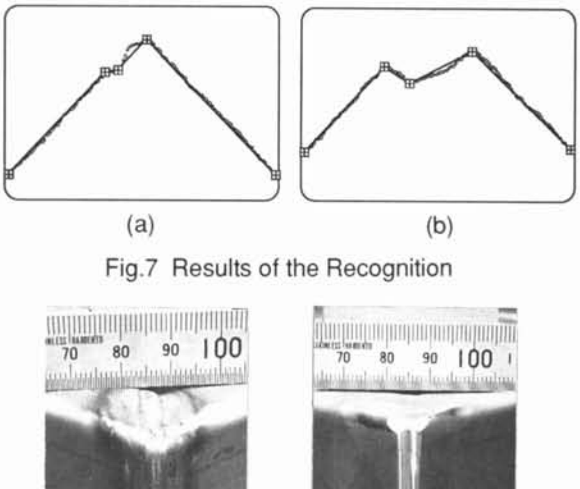
Fig.6 Evaluation of the Deformation

IV. EXPERIMENTAL RESULT

By finding the best deformed template that gives the minimal total deformation quantity, the corner positions of left and right plate are correctly defined, and the gap and mismatch shown in Fig.3 can be measured. This algorithm can work at high speed because it uses only one template which simply models the target shape. The matching process is accelerated by the dynamic programming method and the sequential similarity detection method. The processing time for one image is about 60msec-80msec without using a special processing hardware. The processing speed is fast enough for the control of a robot. The algorithm also has high immunity against the sensor errors because the "total deformation quantity" is not sensitive to local characteristics such as the ones shown in Fig.4(d). The results of some experiments proves the performance of the algorithm as shown in Fig.7(a)-(b). The accuracy of the measured gap, mismatch and tracking position is less than 0.1mm. It satisfies the requirement of this system.

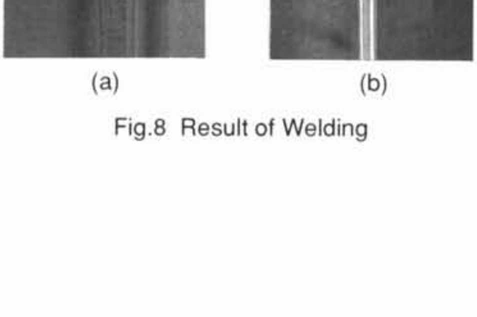
When the analyzed image does not come from the seam to be welded, the total deformation quantity that correspond to the best matching is large. For example, when the sensor scans the top of the work piece shown in Fig.2, the total deformation quantity will be 10 times larger than the total deformation quantity of the images from the seam. By using this characteristic, the ASP/EOS capture is achieved. The accuracy of the ASP/EOS capture correspond to the distance between each scanned lines. In case of our system, it is around 0.5mm.

Fig.8(a) shows the result of the adaptive welding. Fig.8(b) is the appearance after the oxide film was removed. The appearance of the seam is extremely good, and it does not need any finish work by human workers.



(a) (b)

Fig.7 Results of the Recognition



(a) (b)

Fig.8 Result of Welding

V. CONCLUSION

A flexible, robust and fast recognition algorithm for the shape recognition was presented. The deformable template described in this paper is applicable not only for corner joints but also the other type of joints, such as lap, butt, V-groove, and so on. Moreover, the algorithm are also possible to be applied for another shape recognition of deformable objects such as electric wire.

The system described in this paper is already running in our factory. From the result of the running tests in the factory, it was confirmed that our welding system can achieve the high quality welding for all work pieces used in the work cell.

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