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A Method of Robust Seam Feature Detection from Profiles for Robotic Sealing

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Abstract

In industrial assembly lines, seam sealing is a painting process used for making watertight seals or for preventing rusting. In the process, sealant is painted on seams located at the joints of pressed metal parts. We developed a sealing robot system that adjusts the sealing gun motion adaptively to the seam position sensed by a range sensor (a scanning laser rangefinder which senses profile range data). In this paper, we propose a high-speed and highly reliable algorithm for seam position computation from the sensed profile range data around the seam. It is proved experimentally that the sealing robot system used with the developed algorithm is very effective, especially for reducing wasted sealant.

1 Introduction

In industrial assembly lines like those for automobile body manufacturing, sealing is an important process where sealant is painted on seams between the joints of pressed metal plate parts. The purpose of the sealing is to make the seam watertight or to prevent it from rusting. Manual sealing is very difficult because the curved seams are too complex to trace by hand at high-speed. (An example of a seam is shown in **Figure 1**.) Most of the sealing process has therefore already been automated by using teaching-playback robots. However, these robots waste a large amount of sealant when adapting to changes in the workpiece location or shape. So in order to reduce the amount of wasted sealant, a tracking robot system with a vision sensor that can accurately determine the seam position has been greatly needed.

Some robotic sealing technologies featuring sensors have been proposed. Most of them (eg.[1]) are used to locate the workpiece position/orientation error so as to adjust the robot teaching data by sensing several points on the objective workpiece. However, these methods have certain restrictions. Because they do not detect each seam position itself and because the spatial relation between the sensed points and the target seams may not be rigid, the inferred seam positions may be inaccurate. Seam tracking methods that directly sense the seam position for real-time robot control have therefore been investigated[2]. Yet this method does not seem applicable to real manufacturing situations, because it assumes only the appearance of very simple seam shapes.

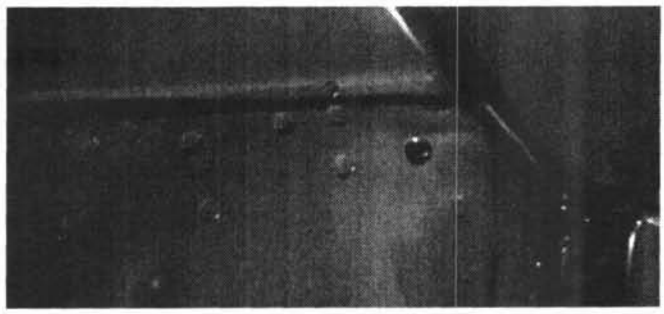

Figure 1: View of a typical seam.

We have developed a real-time seam-tracking robot system which directly senses the target seam position[3]. In the system, we use a highly reliable algorithm for computing seam position from sensed profile-range data. The algorithm is mainly described in this paper. The key topic of the algorithm is the use of an invariant feature of sensed seam shapes, which enables it to measure the seam positions even if the seam shapes change successively. The profile-range data is sensed by a high-speed scanning laser range sensor next to the sealing gun mounted on a robot arm. The configuration of the seam-tracking system is shown in **Figure 2**.

In the next section, we describe the model of a seam profile pattern sensed by the laser range sensor and the algorithm which detects the position where the sealing gun is directed (seam feature). In section 3, the experimental results for workpieces are shown and the efficiency is discussed. Finally, concluding remarks are made in section 4.

2 The Algorithm

Our algorithm does not assume any geometrical models of the seam shape in the objective profile-

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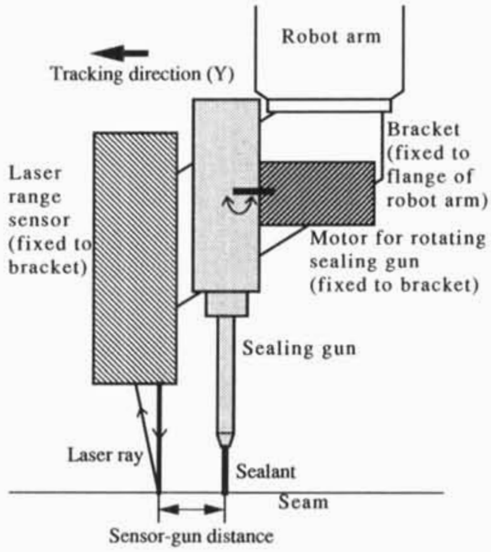

Figure 2: Seam-tracking system configuration with laser range sensor.

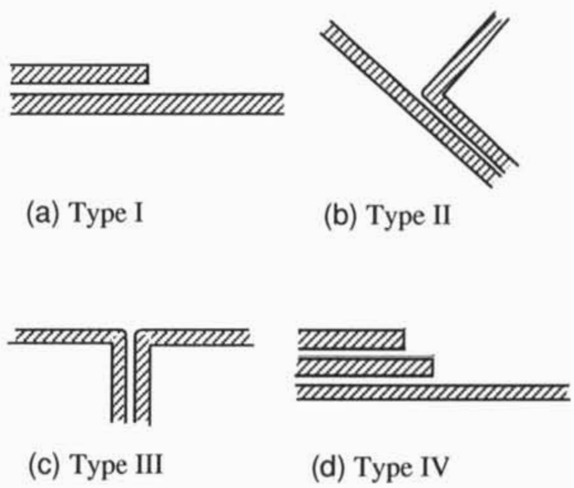

Figure 3: Typical four patterns of seam profiles.

range data sensed around the seam. Instead, it detects jumps in the profile-range data since these are the invariant features of seams. After careful research on the seam shapes appearing in an automotive body, we classified the shapes into four patterns as shown in **Figure 3**. Examples of the sensed profile-range data of the four patterns are illustrated in **Figure 4**. As you can see, jumps appear clearly in all of the data. Our algorithm first detects jumps from the sensed data, and then computes the seam position (strictly speaking, the position where the sealing gun is directed) and finally rejects the positions of uncertain seams caused by the confusing neighboring shapes of burrs or holes.

We apply a very simple statistical approach for jump detection. Assuming the working distance between the sensing origin and the sensor is fairly large compared to the scanning width of the laser ray, we can approximate the scanning beam rays to be parallel to each other. In this case, if the object were planar, the points where the sensor-to-surface range is sensed (we call them range points hereafter) would lie at regular intervals. Even though the object is not planar, but a continuously curved shape, the intervals between the neighboring range point pairs change only slightly and smoothly if the scanning angle is not so large (like for our sensor). Therefore we can assume the distribution of the intervals is Gaussian. On the other hand, the interval between a neighboring range point pair across the jump is much larger than the mean of the distribution.

Based on the above observation, we extract the neighboring range point pairs whose intervals exceed a threshold, given by

$$Th = K\sigma + \mu \quad ,$$

where the distribution of the intervals obeys a Gaussian function with mean μ and standard deviation σ. The extracted pair is considered as a jump.

If the number of the detected jump is one, the seam position where the sealing gun should be directed is the center of the jump. If the number is two, a Type IV seam is sensed. Then we compute the center of the centers of the two jumps as the seam position. In this case, if the two centers are relatively distant, the seam position is not output. If no jumps are detected from the profile-range sensor, we try to detect a bending point in the data because the seam may be sensed as V-type jump.

The algorithm described above is simple, but not very robust against noise in the profile-range data, and may also make mistakes for nearby seam-like shapes, such as burrs, because the seam position is determined only from very local information, namely from one scanning frame of profile range data. However, typical seams are continuous in the tracking direction in a sealing task. To select the valid results, we apply the following operations derived from this continuous nature.

- limitation of the field of view of the profile data in the scanning direction:
  If the seam position can be detected in a sequence of n scanning frames, the field of view of the sensed profile r_n is reduced as

  $$r_n = k^n r_b \quad ,$$

  where k is a positive constant less than 1 and r_b is the original (widest) field of view of the sensor.

- checking the adjacency of inter-scanning-frame seam positions:
  If the current seam position is further from the seam position in the previous scanning frame

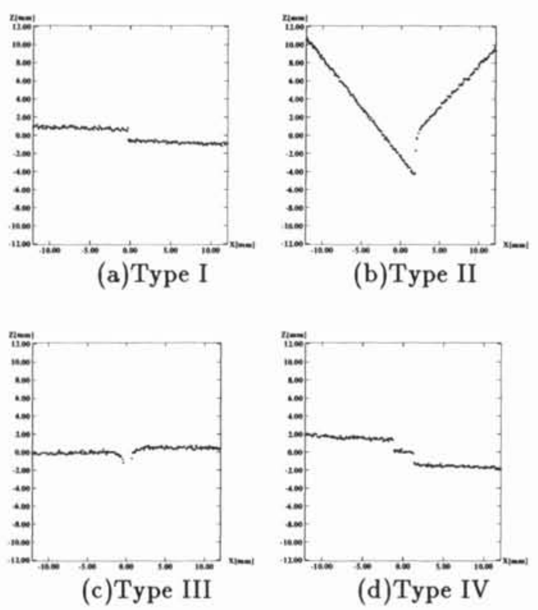

Figure 4: Sensed profile data of typical four seams.

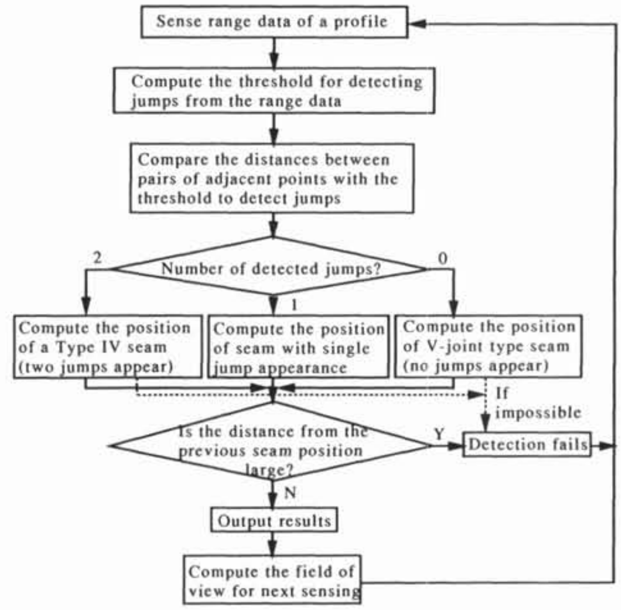

Figure 5: Algorithm flow of the seam detection method.

than a distance threshold determined experimentally, the current seam position is discarded since the continuity is not satisfied.

The flow of the algorithm is illustrated in **Figure 2**. This algorithm is aimed to be used in sensing for real-time tracking robotic tasks with fast robot motion. The speed of the robot motion for sealing is up to 400 mm/s, which is more than 10 times faster than for welding. So it is necessary to determine the seam position from the sensed profile data very quickly. The proposed algorithm is sufficiently simple for real-time sensing.

3 Experimental Results and Discussion

In order to clarify the efficiency of the seam detection, we performed sensing experiments on seams in the engine compartment of a white automobile body. We used a laser range sensor (**Figure 7**) developed by NTT and NTT Fanet systems[4]. In the sensor head, a scanning Galvano mirror rotates through a small angle to scan the laser beam over the object. (See the optical system in **Figure 6**.) The sensor senses the profile-range data containing 256 range points in one scan. The sensor controller includes a DSP (TI TMS320C30) for processing sensed profile-range data. Its laser scanning period is about 8 ms and the processing time when our algorithm works on the DSP is also about 8 ms; so the total sensing frequency is approximately 66 Hz. Other specifications are shown in **Table 1**.

First, we tried the proposed algorithm in the case of various test samples of seams selected from the

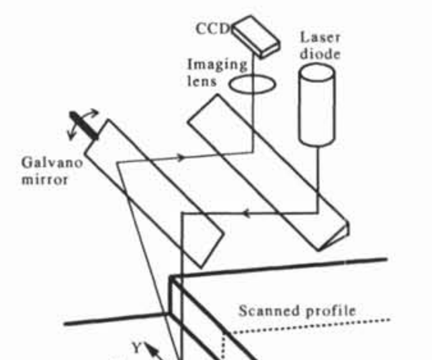

Figure 6: Optical system of the scanning laser range sensor.

item		specification
light source	type of laser	semiconductor (780nm)
	power	30mW
sensing scope	working distance	135mm
	scanning width (X)	±15mm
	depth (Z)	±15mm
response	sampling	16ms (incl. computation)

Table 1: Specifications of the range sensor.

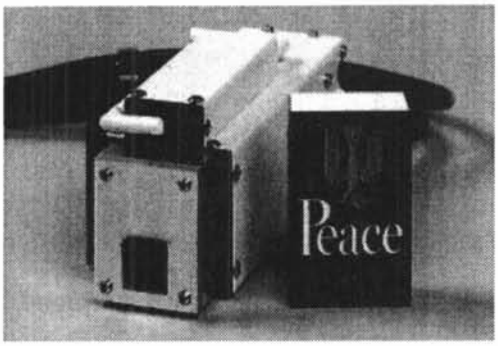

Figure 7: Scanning laser range profile sensor.

seam line no.	1st trial		2nd trial		3rd trial	
	sensed [scans]	detection rate [%]	sensed [scans]	detection rate [%]	sensed [scans]	detection rate [%]
1	86	98.8	86	98.8	85	100.0
2	26	100.0	26	100.0	26	100.0
3	44	100.0	44	100.0	44	100.0
4	46	69.6	46	76.1	46	95.7
5	196	98.0	196	98.5	196	100.0
6	22	100.0	22	100.0	21	100.0
7	39	100.0	39	100.0	38	100.0
8	57	100.0	57	100.0	58	98.3
9	26	100.0	25	100.0	26	100.0
10	32	100.0	32	100.0	32	100.0
11	23	100.0	23	100.0	23	100.0
12	31	100.0	32	100.0	32	100.0
13	35	100.0	35	100.0	35	100.0
14	25	100.0	26	100.0	26	100.0

Table 2: Experimental results for a workpiece of an automobile body. (The speed of robot motion is 400 mm/s.)

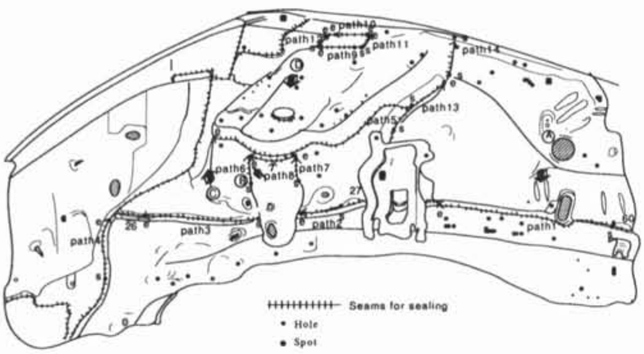

Figure 8: Path configuration in a workpiece.

patterns of the typical four types. 1,000 profiles are sensed for each shape in stable a situation; namely the sensor and the objects were set on a stabilized table. The detection rates of the algorithm were 100% for all the seam shapes, and therefore, the potential of the algorithm in a stable situation was confirmed.

Next we set the sensor onto a flange of a 6DOF robot arm and moved it along 14 seam lines to sense the seam profiles. The speed of robot motion was set at 400 mm/s. The sequences of the robot motion which are called paths are illustrated in **Figure 8**.

The profiles changed in a variety of patterns. Even for a real workpiece, our detection program worked well for most of the seam lines. The detection rates are shown in **Table 2**. Except for the seam line #4, the detection rates were close to 100%. Note that even though the detection rates were not perfect, robotic sealing will work adequately if the false-detection rate is zero.

4 Conclusion

This sealing gun with the sensor can track the detected seam at speeds as high as 400 mm/s. Experimental results showed that the sealing system with our sensing algorithm is very effective and in particular should reduce sealant wastage. Field testing of the sealing system with almost 10,000 bodies on an automobile sealing line has been done and the results show not only significant sealant cost reduction, but also reliable system performance.

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