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# Automatic Control of Arc Welding (Report V)
# —Application of Digital Picture Processing Technique to Automatic Control —

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**Abstract**

*The method, by which the various visual pictures of arc welding are converted into digital data, fed to the computer through TV camera, processed with picture processing technique and necessary informations are extracted, and the arized problem are reported.*

## 1. Introduction

The method of automatic control for arc welding, in which detection of the joint configuration, of the weld line position, of the molten pool condition had been made by use of the image obtained by the light generated from welding arc, had already been reported[1),2),3)]. If sensed and controlled variables are simple, the method described in these reports is applicable in practical use, it is necessary, however, to install logical functional device of higher degree in the automatic control system, in case more complex, more difficult or more accurate detection and control are required. The studies are made to establish the algorithm that should be pocessed in such logical functional device. It may be useful that we apply the memorial function and the logical function of the digital computer to use the visual information, which is obtained at the arc welding, effectively and perform the proper automatic control of arc welding.

In this paper, the method, by which the various visual pictures of arc welding are converted into digital date, fed to the computer through TV camera, processed with picture processing technique and necessary informations are extracted, and the arised problem are reported.

The paper consists as follows.

In the first part, the visual information processing system and the picture data input method are described. The sampling rate of the video signal from TV camera and the bit of analogue digital conversion are investigated on the five typical patterns of the arc welding picture in the next part. The numerical differential operators as the preprocessing operator are also investigated. The performance to clarify the contour of the objects in the picture is tested on the several differential operators for this purpose.

As the example of the necessary information extraction, the algorithm to extract the straight lines from this preprocessed picture data is shown. It can be related to the practical problem such as the sensing of the configuration and the position of the prepared joint at the work piece, of the position of the electrode wire and of the position and the condition of the molten pool. This algorithm is applied to the above mentioned picture.

The real time processing algorithm is shown to demonstrate the ability of the real time sensing in the final part of the paper. The example for the real time extraction of the necessary information from time sequentially transmitted picture data is also shown by applying the algorithm to the arc welding picture.

## 2. Visual Information Processing System

The block diagram of the visual information processing system is shown in Fig. 1. The video aignal

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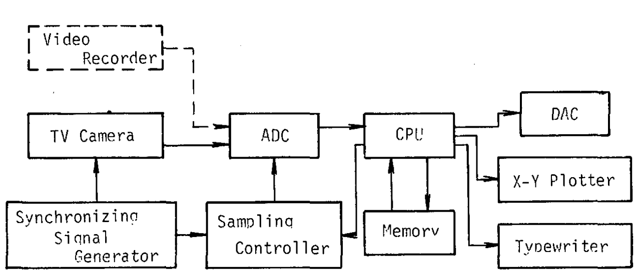



Fig. 1 Block diagram of picture processing system.

from TV camera or video recorder is input to the central processing unit (CPU) through analogue digital converter (ADC) and stored in memory after processing by simple arithmetic operation. The level for analogue digital conversion can be set arbitrarily at 8 and less bits. Sampling of ADC is controlled by the sampling controller which runs synchronizing with the vertical and the horizontal signal for TV camera generated from the synchronizing signal generator.

Sampling control by the controller is shown in Fig. 2.

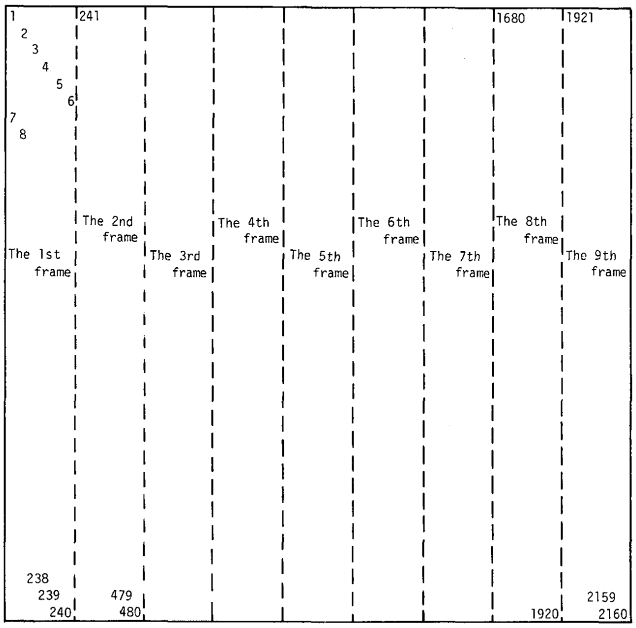



Fig. 2 Schematic explanation for sampling of video data.

Sampling for video signal begins at left upper. Each datum is sampled on the horizontal scanning line one by one in its numerical order shown in Fig. 2 and 240 points ( 1 ~ 240 ) are sampled on 240 scanning lines of the first frame of picture. Next 240 points are sampled on the second frame of picture subsequently. Sampling is performed in the similar manner successively and a total of $240 \times 9 = 2160$ points are sampled from the first to the 9th frame. If we assume that all the points whose N values are equal exist in the same row, it is implied that the digital picture of 2160 picture elements (40rows x 54columns) is synthesized from the video signal of nine picture frames. The value of N is given by the equation

$$N = [\{ n - 240 (F - 1)\} / 6] \qquad (1)$$

where

n; numerical order of the sampled point.

F; picture frame number

[ ] ; Gauss' notation

The period required for sampling on 2160 points is 1/60 (sec) (period required for one frame scanning) x 9 = 150 (msec). The analogue digital converter transmits the interrupt signal to CPU immediately after the conversion ends, so this signal is transmitted at intervals of about 60 ($\mu$sec), the converted datum is input in CPU at each interruption.

The merits and the demerits of such sampling control method are as follows.

Merits

(1) It is possible to perform the preprocessing operation such as smoothing, filtering etc., running parallel with the data input in CPU as there is considerable margin in the time interval for the each datum transmission.

(2) It is unnecessary to use high speed ADC.

(3) The apparatus becomes simple as it is not required to install extra buffer memory at ADC.

Demerits

(1) If the image changes rapidly, the trouble may occur due to the synthesized picture from several picture frames.

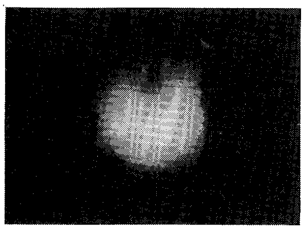
(2) It requires considerable time to sample on all the points of the picture.

It is seemed that the period of 150 (msec) is not so long when we think of the present automatic control for arc welding. The apparatus becomes cheaper, on the other hand, by the merits (2) and (3), therefore, such method is adopted as the result. The data stored in the memory can be taken out and dispayed with the X-Y plotter or typewriter.

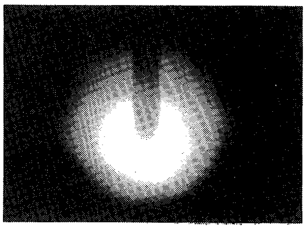
## 3. Conversion to Digital Picture

The conversion to digital picture is investigated on the five typical patterns of the arc welding image shown in Fig. 3. In this figure, the image (a) is obtained at $CO_2$ arc welding of square groove of butt joint, the images (b) and (c) correspond to the welding of the vee groove or horizontal fillet welding, (b) is of $CO_2$ arc and (c) is of MIG arc, the images (d) and (e) are those of square groove welding of $CO_2$ arc whose gap width is narrow, (d) is in the first pass and (e) is in the final pass of multi-layer weld respectively.

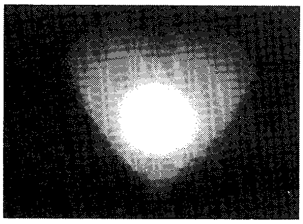
The spacial sampling rate is investigated on these images. Some of the results are shown in Fig. 4, 5 and 6. These figures are the digital pictures, in which Fig. 4, 5 and 6 correspond to Fig. 3 (a), (c) and (d) respectively,



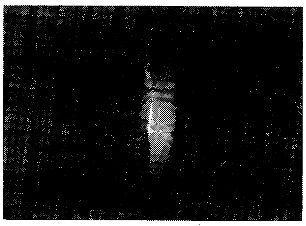
(a)



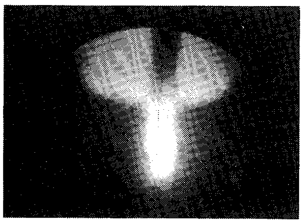
(b)



(c)



(d)

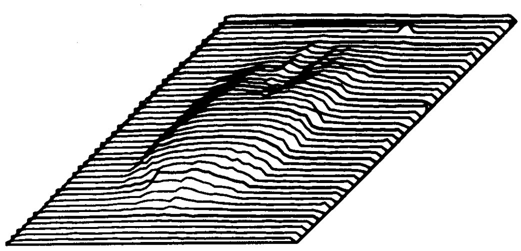


(e)

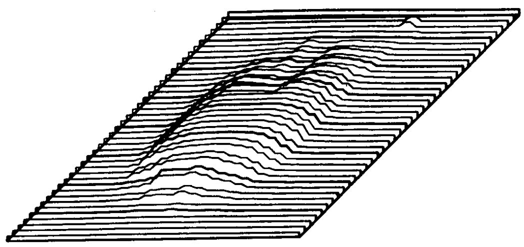
Fig. 3 Five typical patterns of arc welding picture.

and their levels of brightness are expressed stereographically. In these figures, sampling is made on 40rows x 54columns = 2160 points in (a), 20 x 27 = 540 points in (b), 10 x 14 = 140 points in (c) and 5 x 7 = 35 points in (d). It is seen from these figures that sampling on too small number points for the object prevent from expressing its accurate configuration, but the configuration becomes stable against various noises if the analogue digital conversion is made on the small numbers of points with the ADC of considerably slow conversion ability.

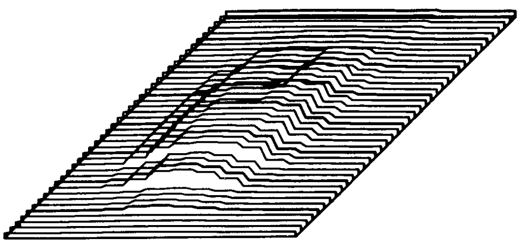
The quantization level for the digital picture is investigated on the same images as shown in Fig. 7, 8 and 9. The level of brightness is expressed with 8 levels in (a), 4 levels in (b) and 2 levels in (c), (d), (e) and (f) of these figures. (In these figures, *cf.* 1 the brightness level is not exactly linear. *cf.* 2 the data on the right column are omitted by the reason that their data are noisy.) The shading threshold level for the binary pictures in (c), (d), (e) and (f) of Fig. 7, 8 and 9 is set at 20% in (c), 40% in (d), 60% in (e) and 80% in (f) of the brightest value in each picture respectively. It is seen from these figures that the accurate configuration can be recognized in such arc welding images with 8 grade level of brightness as shown in Fig. 2, and that care is necessary for binary picture because the image different from original one is obtained if the shading threshold level is set at unsuitable value.



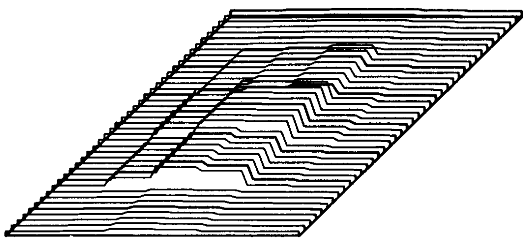
(a)



(b)



(c)



(d)

Fig. 4 Investigation on spacial sampling rate.

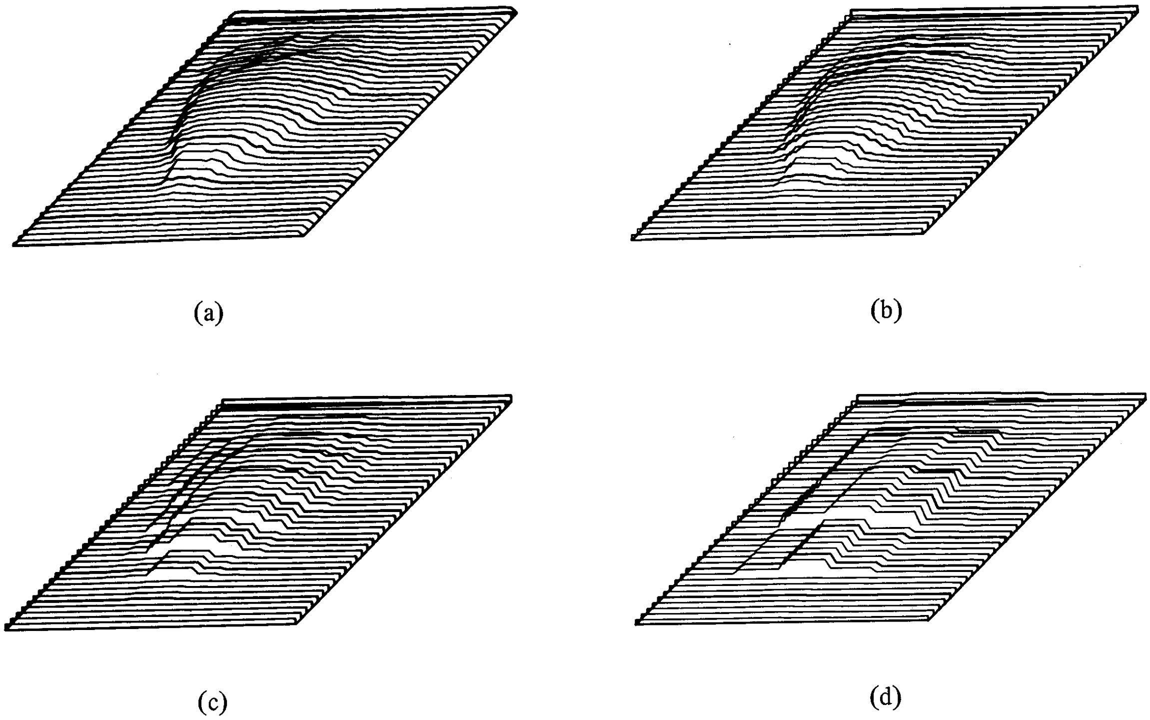



Fig. 5 Investigation on spacial sampling rate.

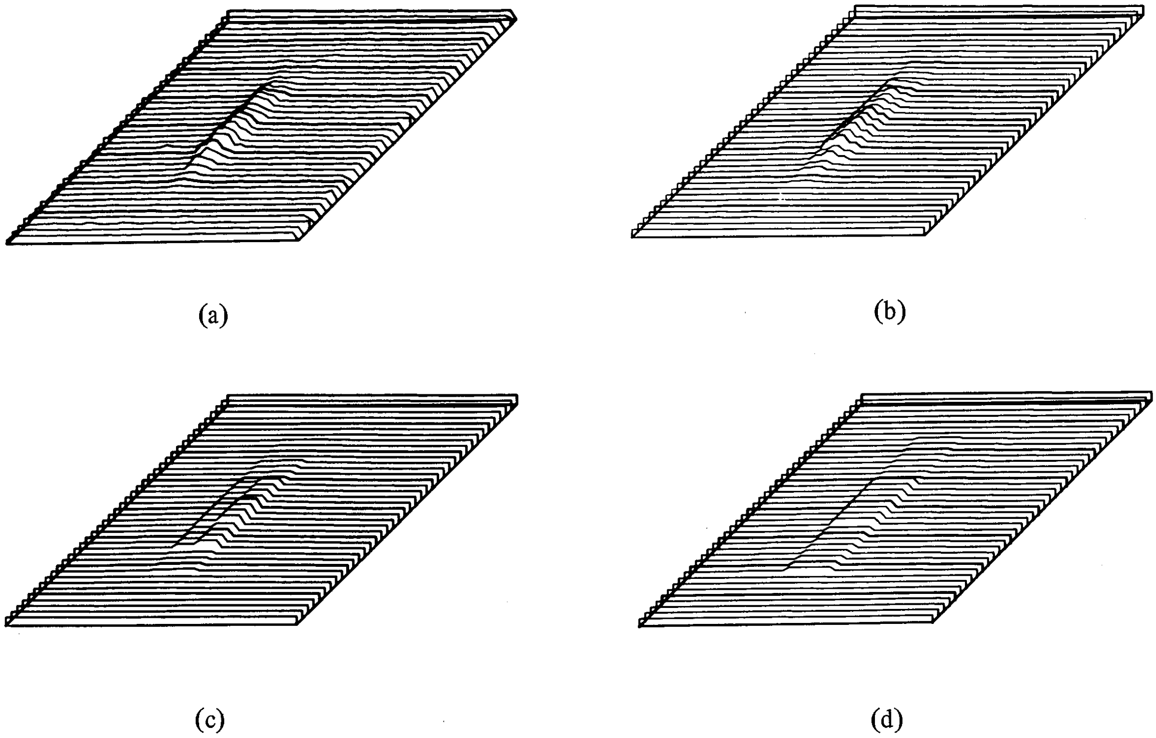



Fig. 6 Investigation on spacial sampling rate.

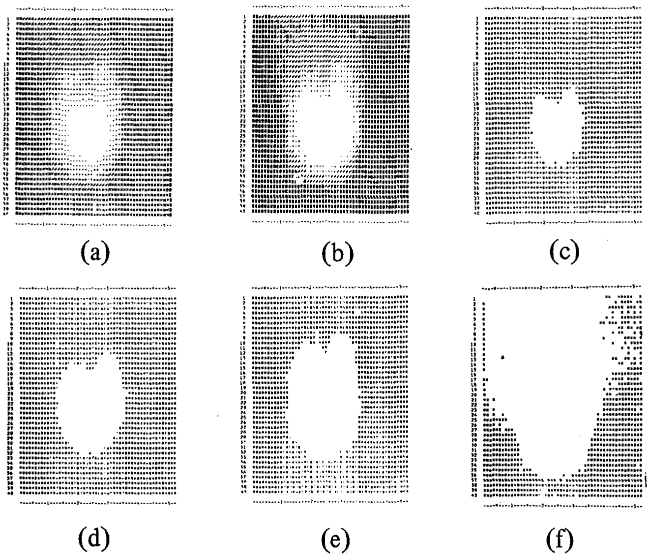



Fig. 7 Investigation on quantization level of digital picture.

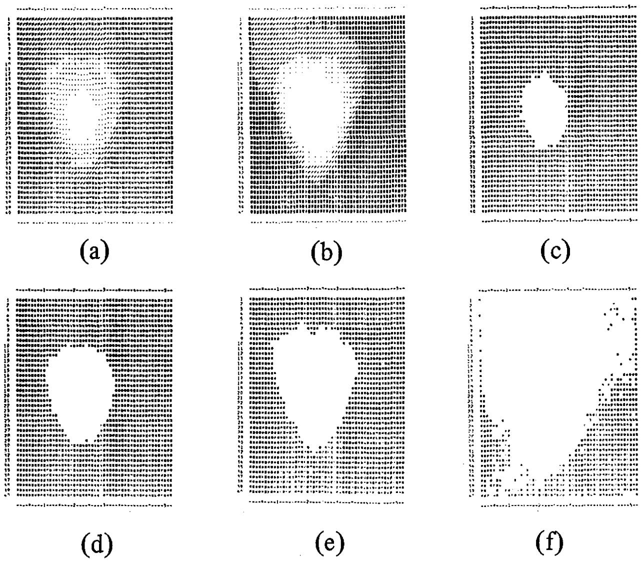



Fig. 8 Investigation on quantization level of digital picture.

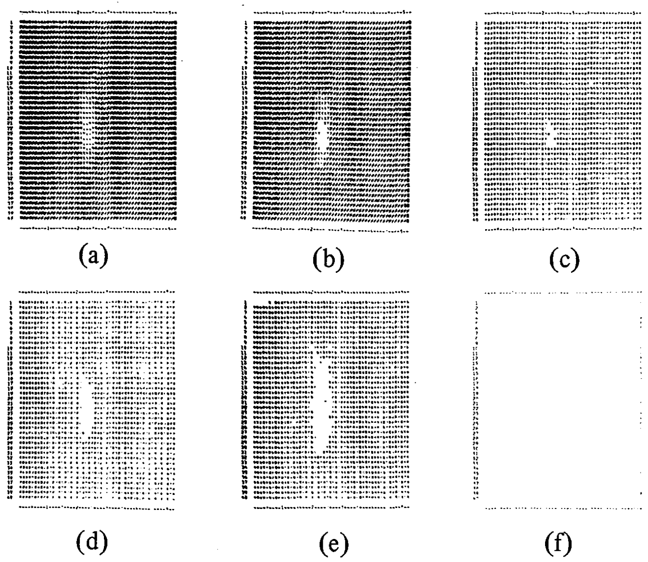



Fig. 9 Investigation on quantization level of digital picture.

## 4. Edge Detection

### 4-1 Preprocessing Differential Operator

Extraction of the contour of the object is needed to recognize its configuration. We must emphasize the contour line by preprocessing the digital picture with the spacial numerical differential operator. The various differential operators have ever been proposed by many researchers[4)-8)]. Investigation is made on these operators. The processed results are shown in Fig. 10, in which the image shown in Fig. 2 (a) is converted into the digital pictures of 2160 points and 8 bits, applied by the various differential operators and expressed with 8 brightness levels. The value of high level is expressed as shade and all the values are normalized with the maximum

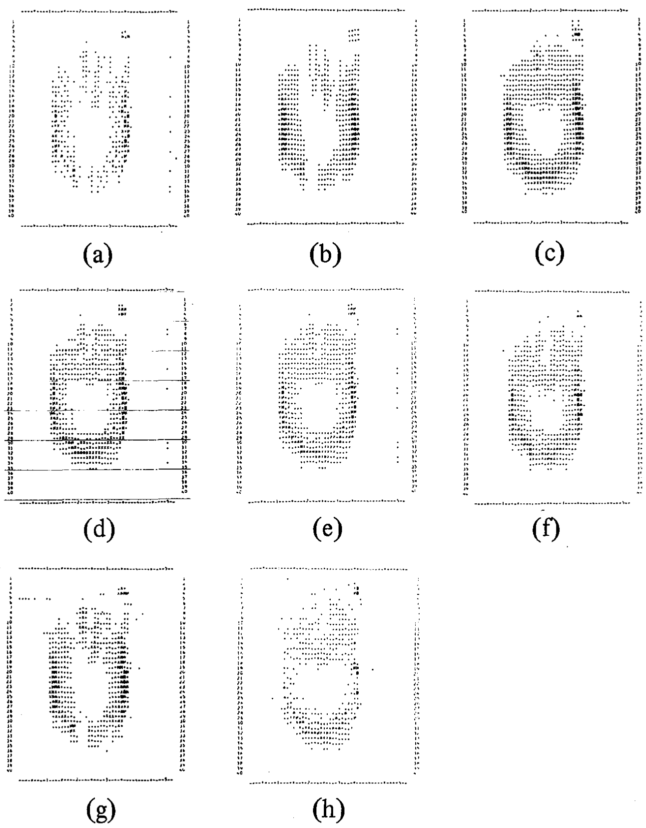



Fig. 10 Investigation on spacial differential operator.

value after differential operation in these figures.

The applied differential operators are given as under;

$$
\left.\begin{array}{ll}
(a) & |A-B| \rightarrow A \\
(b) & |A+D+G-C-F-I| \rightarrow E^{4)} \\
(c) & |E-A|+|E-C|+|E-G|+|E-I| \rightarrow E^{5)} \\
(d) & |A-E|+|B-D| \rightarrow A^{6)} \\
(e) & \sqrt{(A-E)^2+(B-D)^2} \rightarrow A^{7)} \\
(f) & E-\mathrm{Min}\,(A,B,C,D,F,G,H,I) \rightarrow E^{8)} \\
(g) & |B-A|+|B-C| \rightarrow B \\
(h) & |A-D| \rightarrow A
\end{array}\right\} \cdots (2)
$$

The characters as A,B,C,D,E,F,G,H and I experss the array of the digital data as shown in Fig. 11. The allow

| | | |
|---|---|---|
| A | B | C |
| D | E | F |
| G | H | I |

Fig. 11

symbol shows the substitution of the data. As it is clear from Fig. 10 that the difference by the operator is not so remarkable, but the difference becomes clear in the binary level pictures shown in Fig. 12, where the threshold level is set at 40% of the maximum value same as in Fig. 7, 8 and 9 (b). The bottom part of the arc becomes invisible in the pictures processed by such differential operators as (a), (b) and (g) which are sensitive only to the change of brightness in the horizontal direction, on the other hand, the edge configuration of the groove becomes obscue in the picture processed by the operator (h) which is sensitive only to the change of brightness in the vertical direction.

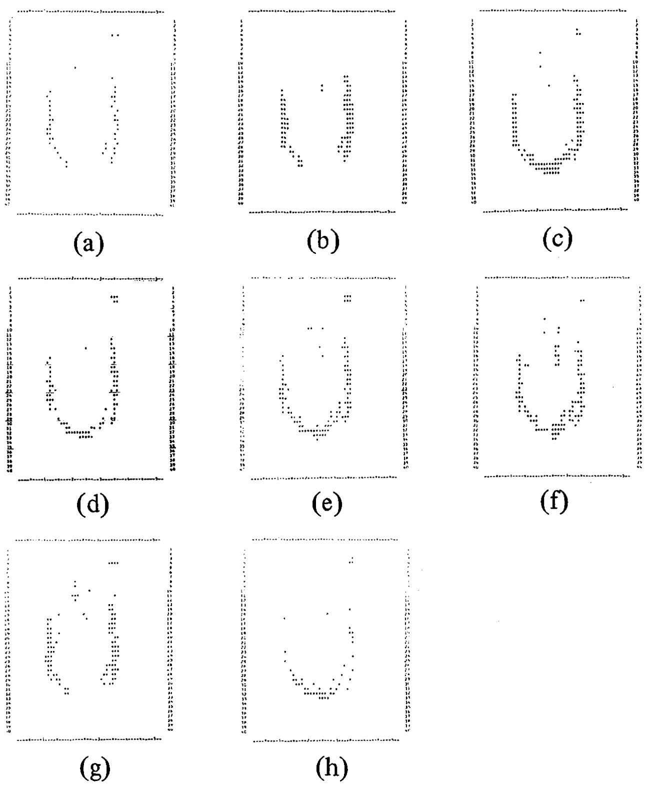
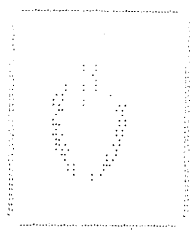
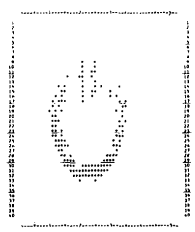



Fig. 12 Investigation on spacial differential operator.



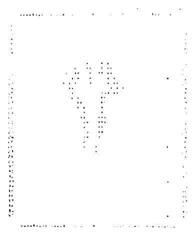
(a)

(a) The differential operator (a) is applied to the image in Fig. 3(b)



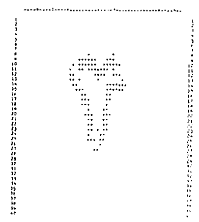
(b)

(b) The differential operator (d) is applied to the image in Fig. 3(b).



(c)

(c) The differential operator (a) is applied to the image in Fig. 3(e).



(d)

(d) The differential operator (d) is applied to the image in Fig. 3(e).

Fig. 13 Investigation on spacial differential operator.

Another example is shown in Fig. 13, in which the simple differential operators (a) (the "horizontal" operator) and (d) (the "crossing" operator) in eqs. (2) are applied to the images corresponding to Fig. 3 (c) and (e). The difference in processing effect by the "horizontal" and the "crossing" operators is clear.

We must be careful for selecting the differential operator according to the purpose of the detection and the configuration of the object.

### 4-2 Edge Detection Algorithm – Extraction of Straight Lines.

We will introduce the algorithm for the detection of

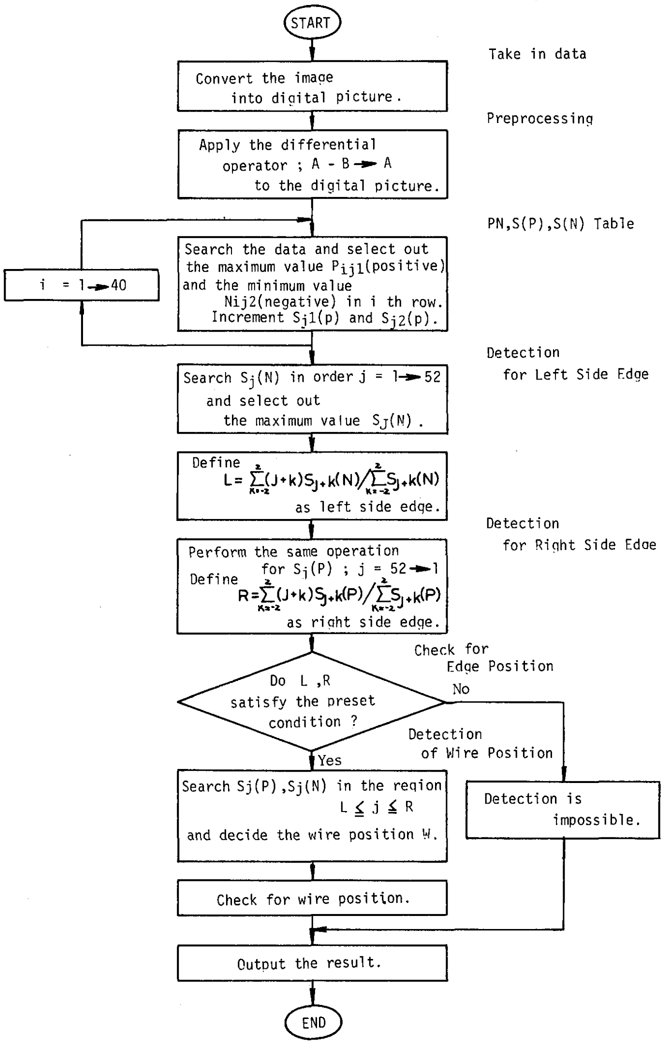



Fig. 14 Flow chart for vertical straight lines extraction.

the position of the groove edge and of the wire in the square groove welding image such as Fig. 3 (a) as an example for the necessary information extraction. It becomes necessary to extract the vertical straight lines from the image in order to detect them. The algorithm for this purpose is shown in Fig. 14 as a flow chart. Following the flow chart, the original image is converted into the digital picture by above mentioned method, taken in the memory of the computer system, and the differential operator is applied to them. We use the simplest operator as

$$A - B \rightarrow A \text{........................} (3)$$

judging from Fig. 10, 12 and 13. The equation (3) is different from the equation (2) (a) in lacking the sign of absolute value off. Then, PN, S(N) and S(P) Table are formed in memory by searching differentiated data. They are displayed with typewriter and shown in Fig. 15. The

```
I    ---------*---------*---------*---------*---------*--
1    ............................P............N..........
2    N.....................P.............................
3    .................................NP.................
4    .................................N.P................
5    .........N...........P..............................
6    ...................................NP...............
7    ....................NP..............................
8    ...................N.P..............................
9    .....................P...N..........................
10   .........................N........P................. *
11   ....................N.............P.................
12   .....................P..N...........................
13   .........................N.......P..................
14   ........................N.......P...................
15   ........................N.........P.................
16   ...........N......................P.................
17   ..........N.......................P.................
18   ...........N......................P.................
19   ...........N.....................P..................
20   ...........N.......................P................ *
21   ...........N......................P.................
22   ............N.....................P.................
23   ...........N.......................P................
24   ..........N........................P................
25   ..........N.......................P.................
26   ...........N......................P.................
27   ...........N.......................P................
28   .............N....................P.................
29   ..............N...................P.................
30   ...............N.................P.................. *
31   .................N...............P..................
32   .................N..............P...................
33   .........................N..P.......................
34   ........................N.P.........................
35   ........................N.P.........................
36   .................N...........P......................
37   ........................N..P........................
38   ........PN..........................................
39   ..........N............................P............
40   .......................N.......P.................... *

S(N)  1 0 0 0 0 4 1 1 0 0 2 0 6 0 0 0 0 0 0 0 0 0 0 0 0 0
       0 0 0 0 2 8 1 1 3 1 0 1 4 0 0 0 2 1 0 0 1 0 0 0 0 0

S(P)  0 0 0 0 1 0 0 0 0 0 0 1 0 2 2 0 2 13 1 0 0 0 0 0 0 0
       0 0 0 0 0 0 0 0 0 0 5 0 0 1 1 1 4 5 0 1 0 0 0 0 0 0
```

Fig. 15 PN, S(N), S(P) Table.

positions of the left edge L and right edge R can be obtained from S(N) and S(P) Table according to the algorithm. The values L and R checked up whether they satisfy the preset condition and if satisfactory, the data between both edges are searched and the operation to detect the wire position is carried out.

We obtain

$L = 11.7$

$R = 35.0$

$W = 23.5$

from the example of Fig. 15.

## 5. Real Time Detection Algorithm

### 5-1 Flow Chart

The algorithm to extract previously mentioned R, L and W values which are necessary information for the control of narrow gap welding and to output the control signal is shown in Fig. 16 as a flow chart. In order to avoid

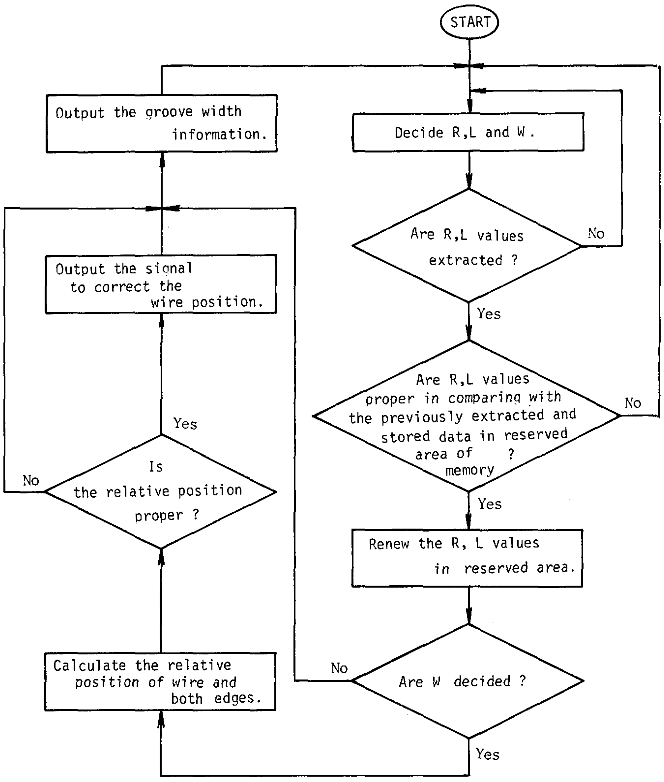



Fig. 16 Flow chart of real time detection algorithm for narrow gap welding.

the misdetection, the obtained R, L values by following the flow chart in Fig. 14 are compared with the reserved values which are decided in previous processing and checked the discontinuity when they change. The relative position of the groove edges and the wire is determined by this algorithm and the information on the width of the groove and signal for correcting the wire position (in case W is obtained) are output.

### 5-2 Real Time Detection

The real time detection of L, R and W values are experimented by the flow chart in Fig. 16 which is coded in assembler language on using the video recording of narrow gap welding process. The result is shown in Fig. 17. In the figures, the characters L, R and W in the same row indicate the horizontal positions of the left and the right groove edges and of the wire respectively and each row corresponds to each signal output moment. The signals are output at an interval of about 200 (msec).

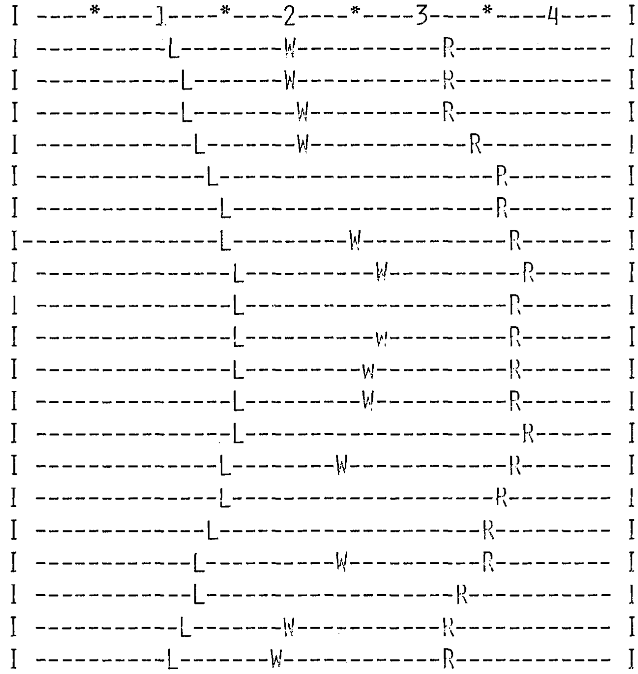


Fig. 17 Result of real time detection.

## 6. Conclusion

1. The economic analogue digital conversion method for video signal from TV camera described in this report is effective to the image obtained during arc welding.
2. The spacial sampling rate and the quantization level of the digital picture must be determined considering the purpose of the detection and configuration of the object.
3. The same consideration as above must be made on the determination of the spacial differential operator. The differential operator of the comparatively simple type is effective in the arc welding picture processing.
4. The algorithm for real time detection is applied to the narrow gap welding and its usefulness is confirmed.
5. The investigation is made on applying to the other kind of welding and on the higher speed processing method. The prospects are bright.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