A Two-Dimensional Positioning System by Use of M-Array

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Abstract: A two-dimensional positioning system by use of an M-array is proposed. An M-array pattern, which is known as one of the two-dimensional pseudo-random array, is attached on an object to be positioned. The M-array pattern is observed by a TV camera and crosscorrelated with the reference M-array. The maximum of the two-dimensional crosscorrelation function is sought by two-dimensional servo system. This method of positioning can be used in very noisy circumstances.

1. Introduction

A two-dimensional (2D) positioning system is widely used in industrial processes such as machining processes, semi-conductor devices and so on. The 2D positioning system is usually used in very clean circumstances, because the detection of the 2D position is easily carried out in those cases. However, in actual industrial processes, we sometimes have to determine and control the 2D position of an object in noisy environment. For example, in machining processes, the work to be positioned is sometimes disposed to dust, oil contamination, or metal chips produced during the machining. Another example is in semiconductor processes. Since LSI devices are now becoming more complex in their circuit architecture and more compact in their size, the 2D positioning system for use in such processes is required to have high precision as well as high performance under noisy circumstances.

This paper describes a method of 2D positioning by use of pseudo-random M-array. An M-array is a 2D array of pseudo-random M-sequence, and its 2D autocorrelation function is known to have a δ-function-like sharp peak at its origin. Making use of this property of M-array, a 2D servo positioning system is designed and its performance is checked to have good quality.

This positioning system has two features:
(1)Non-contact type positioning is realized.
(2)The system can be used under very noisy circumstances, since the crosscorrelation function is used to detect the correct position of the object.

The M-array pattern used in this method can be made by any material including optical or magnetic sheet or even LSI circuit itself. Therefore, this method is expected to be used in several industrial processes.

2. Principle of the method

The basic diagram of the 2D positioning is shown in Fig.1. An M-array pattern, black and white pattern in this case, is attached on an object to be 2D positioned. The M-array pattern is observed by a TV camera, and the image data are fed to a mini-computer through a personal computer and an interface. The image data of the M-array are then crosscorrelated with a reference M-array stored in the mini-computer. The 2D crosscorrelation function between these data is first carried out by use of 2D Fast Fourier Transform(FFT) algorithm, and the peak of the crosscorrelation function is 2D sought roughly by use of X-Y positioning servo. This rough positioning is called here the first stage of the positioning. Then the system proceeds to the second stage, fine and precise positioning in the vicinity of the peak of the crosscorrelation function. In this stage, 5×5 elements of the image data are added together to obtain the added M-array(Kashiwagi *et.al.*, 1987), which is crosscorrelated with the reference added M-array in the vicinity of the peak. We showed in the reference (1) that this added M-array is very useful in following up the peak of correlation function since the correlation function of the added M-array has enogh width which enables us to get information about the direction of control. By use of this added M-array, the peak seeking is carried out precisely in the second stage. This second stage is, if necessary, repeated until no more correction of the positioning is needed.

3. Detection of phase of M-array

A two dimensional pseudo-random M-array can be obtained, when the period of an M-sequence $N = 2^n - 1$ is written as

$$N = N_1 \cdot N_2, \quad N_1 = 2^k_1 - 1$$

$$N_2 = N/N_1, \quad N = 2^{k_1 k_2} - 1 \qquad (1)$$

For example, when $N = 2^n - 1 = 3 \times 5 (k_1 = k_2 = 2)$, the M-array is obtained as follows.

$$\begin{bmatrix} m_0 & m_6 & m_{12} & m_3 & m_9 \\ m_{10} & m_1 & m_7 & m_{13} & m_4 \\ m_5 & m_{11} & m_2 & m_8 & m_{14} \end{bmatrix} \qquad (2)$$

When the element of M-array of i-th row, j-th column is denoted as $m(i,j)$ $(m(i,j) = 1 \; or \; -1)$, the normalized

2D autocorrelation function of $m(i,j)$ is given by

$$\Phi(k,l) = \begin{cases} 1 & \text{for k=l=0,N,2N,...} \\ -1/N & \text{otherwise} \end{cases} \qquad (3)$$

The detection of phase of a given M-array is carried out by making use of this correlation property of M-array. In our TV camera system, 240×150 pixels if image data are fed to mini-computer. Out of these data, 128×128 pixels are taken out for image processing. The M-array pattern used here is of 8 order(15×17 elements, 30mm×34mm in real size) as shown in Fig.2. Here one element of the M-array is a square of 2mm×2mm, which is taken into the mini-computer as 4×4 pixels. That is to say, one pixel in the image data corresponds to 0.5mm in real size. It is quite easy task to make this correspondence as precise as you want. The 128×128 pixel image including M-array is crosscorrelated with a reference M-array stored in the computer by use of 2D FFT and inverse FFT. In order to reduce the time required to calculate 2D FFT, we sampled every 4 pixels of the image data. And only the sampled data are used for calculation.

Fig.3 shows one example of thus obtained crosscorrelation function. We see the sharp peak at the right phase of the observed M-array. The X-Y table is controlled by 2D servo systems so as for the crosscorrelation to be a maximum(The first stage). Taking only those image data from the vicinity of the peak of the crosscorrelation function, the added M-array is first obtained by adding 5×5 pixels and crosscorrelated with the reference added M-array in the computer. From this crosscorrelation function of the added M-array, the precise adjustment of the peak following system is carried out(The second stage). Even when the object to be positioned is moved to some place, the positioning system follows up the right position repeating the first and second stages.

4. Performance under noisy environment

Since the autocorrelation function of the M-array has a very sharp peak at its origin, the positioning system by use of M-array has a good performance under noisy environment. In order to test the noise property of the positioning system, we made several experiments putting several obstacles on the M-array pattern, as shown in Fig.4. The left two examples in Fig.4 are in case where some black obstacles are put on the M-array. The right two examples are with white obstacles. Fig.5 shows the crosscorrelation functions in case where 30%,50%,70% and 80% area of M-array pattern is contaminated by such noise as shown in Fig.4. We see the peak of the correlation function appears clearly, from which the 2D positioning system works quite well. We have checked that even 80% area of the M-array pattern is contaminated by some noise, the positioning system has enough performance to control the X-Y servo system.

5. Time required for positioning

The proto-type positioning system which we have made has the following performance as far as the required time is concerned.

The TV camera sends 240×150 pixels(each pixel has 4 grade) to the memory of the mini-computer through 8 bit parallel transmission terminal and GPIB, which takes about 3 seconds. The 2D FFT using sampled data takes 5 seconds. So the first stage takes about 8 seconds. The calculation of the correlation function of the added M-array in which 5×5 pixels are added, takes 20 seconds. So the second stage takes 23 seconds, which must be more shortened in order to get a fast positioning system. We are now trying to calculate the correlation function of the added M-array by use of some optical method.

6. Example of positioning process

Table 1 shows an example of actual positioning process. The object with an M-array is first displaced to (12.5mm,9.5mm) position from the original position. We would like to see how the positioning system controls X-Y table in order to get to the original position (0,0). In the first stage, the X-Y table is moved by -14.0mm and -10.0mm in X and Y direction, respectively. In the second stage, the precise adjustment is done to give 1.5mm and 0.5mm movement in X and Y direction, respectively. Here the correct positioning is carried out and no more correction is needed in the third stage.

7. Conclusion

The 2D autocorrelation function of a pseudo-random M-array has a very sharp peak at its origin. Making use of this property of M-array, a non-contact type 2D positioning system is designed and checked by its accuracy, speed of following up and noise performance. It is shown that although some improvements are necessary for practical use in the speed of following up, the proto-type positioning system has enough accuracy as expected, and can be used in very noisy cercumstances such as in case where 80% area of the M-array pattern is contaminated by some noise. The improvement of the speed of following up is now being considered by use of some optical method in the calculation of the added M-array. This method of 2D positioning is expected to be used widely in machining processes or semiconductor industries even in noisy environment.

References

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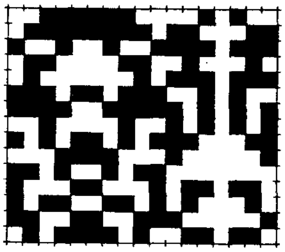

FIG.2 AN EXAMPLE OF M-ARRAY PATTERN

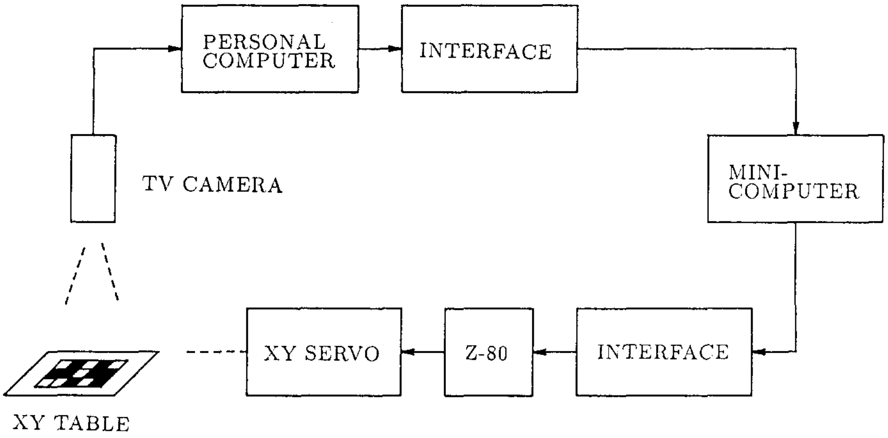

FIG.1 SCHEMATIC DIAGRAM OF THE 2D POSITIONING SYSTEM

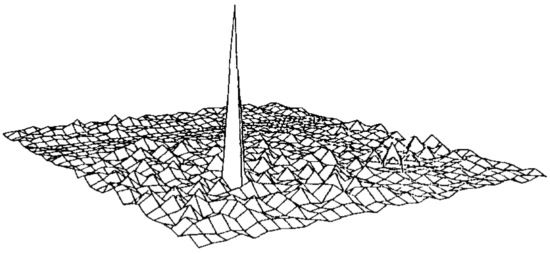

FIG.3 2D CROSSCORRELATION FUNCTION BETWEEN THE OBSERVED M-ARRAY AND THE REFERENCE

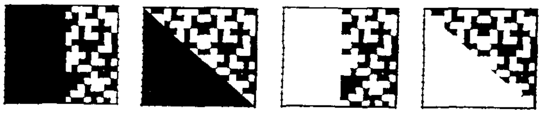

FIG.4 VARIOUS NOISE ON THE M-ARRAY PATTERN

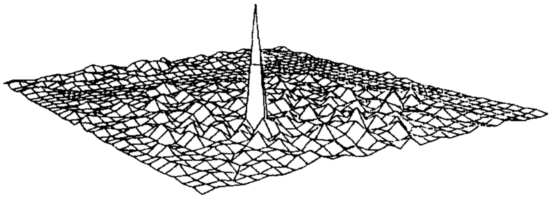

Fig.5(a) Crosscorrelation function when 30% area of the M-array is contaminated by noise

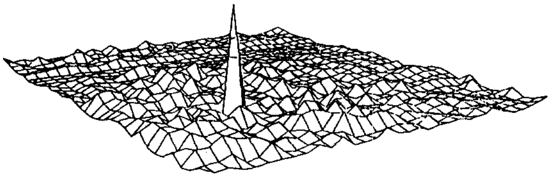

Fig.5(b) Crosscorrelation function when 50% area of the M-array is contaminated by noise

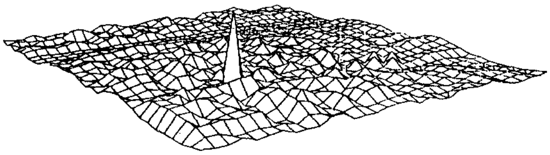

Fig.5(c) Crosscorrelation function when 70% area of the M-array is contaminated by noise

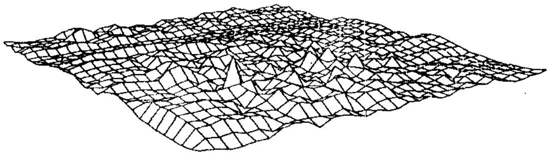

Fig.5(d) Crosscorrelation function when 80% area of the M-array is contaminated by noise

Table 1 An example of positioning process

stage	**1**	**2**	**3**
dx(mm)	-14.0	1.5	0.0
dy(mm)	-10.0	0.5	0.0