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# A Two-Dimensional Positioning System by Use of Correlation of Vague M-Arrays

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**Abstract:** This paper describes a new method for two-dimensional(2D) positioning system by use of crosscorrelation of vague M-arrays. An M-array pattern is attached on an object to be positioned and it is observed by a TV camera in out-of-focus condition. The crosscorrelation between the observed image data and the reference M-array gives us the information about the 2D position of the object.

## 1. Introduction

A two-dimensional (2D) positioning system is widely used in industrial processes such as semiconductor devices and so on. The authors proposed a new 2D positioning system by use of M-array in '88KACC. In this system, the property of M-array is used in that the 2D autocorrelation of M-array has a very sharp peak at its origin. This property plays an important role in the precise positioning, but it sometimes occurs the case there the autocorrelation of M-array is too sharp to be used for servo-controlling the two-dimensional position.

In this paper, the authors propose a new method of 2D positioning system by use of autocorrelation of vague M-array which is observed with a TV camera in out-of-focus condition. An M-array pattern is attached on an object which is to be XY-positioned. The object is observed with a TV camera which is at first in out-of-focus condition. Then the observed image data including the vague M-array is crosscorrelated with the reference M-array in a computer. Since it is known that the autocorrelation of the vague M-array has a larger width in the vicinity of its origin than that of pure M-array, the vague M-array gives wider error signal for XY servo system, so it is more suited to be used for servo controlled positioning in an early stage. The proto-type positioning system is constructed and its performance is checked for various condition. The results of the experiment show that the follow up speed is much improved compared with the previous one.

## 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. Here the focus of TV camera is at first set to out-of-focus condition so that the image data from TV camera become something like the added M-array(Kashiwagi *et.al.*, 1987). The observed image data of the M-array are then crosscorrelated with a reference M-array stored in the mini-computer. The 2D crosscorrelation function is first calculated 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. We showed in the reference (3) that the added M-array is very useful in following up the peak of correlation function since the correlation function of the added M-array has enough width which enables us to get information about the direction of control even when the displacement of the object from the right position is large. By use of the autocorrelation of vague M-array instead of added M-array, the peak seeking is carried out rapidly and precisely in the second stage. In this stage, the focus of the TV camera is controlled with Z-axis servo so that when the X-Y positioning come close to the vicinity of the true peak, TV camera is focused well,and when the positioning is apart from the peak, TV camera is out-of-focus condition.

## 3. Detection of phase of M-array

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

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

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 of image data are fed to a 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 reference (1). 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 2 pixels of the image data. And only the sampled data are used for calculation.

Fig.2 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). Then, several crosscorrelation values of the vicinity of its peak are calculated. From these crosscorrelation values, the precise adjustment of the peak following system is carried out(The second stage). Note that the Z-axis control for the focus is also carried out at the same time X-Y servo controls the X-Y axes. 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. Effect of focusing of TV camera

When the TV camera looking at the M-array pattern is in out-of-focus condition, the observed data becomes something like the added M-array pattern, since the out-of-focus condition makes the original image added together within a cirtain circle. Therefore, the out-of-focus condition of TV camera plays a role of addition within a circle optically. Thus the added M-array can be obtained optically without calculating it in a computer. The effect of focusing of TV camera is shown in Fig.3 through Fig.4 , where the diameter of the added area of circle is changed. As is seen from these figures, the width of the peak of the crosscorrelation fucntion becomes large as the focus becomes in out-of-focus condition.

## 5. Positioning speed

The positioning system is actually constructed and several experiments are carried out to check the availability of this system. The positioning speed is very much improved compared with the previous system. The TV camera sends 240×150 pixels(each pixel has 16 grades) to the memory of the minicomputer through GPIB, which takes about 1 second. The 2D FFT using sampled data with sampling interval of 2 takes about 10 seconds. Thus the first stage(rough positioning) takes about 11 seconds. Since the second stage(precise positioning) needs several of the crosscorrrelation values in the vicinity of the peak and we need not calculate the added M-array in a computer, the second stage require only 2 seconds. We see much improvement in the positioning speed, since the previous system needed 23 seconds for the second stage.

## 6. Experimental result of positioning

One of the feature of our positioning system using M-array is that the system is robust to noise contamination. In our previous paper, it is shown that the positioning system works well even 80 % area of the M-array pattern is contaminated by some noise. Here, one of the experimental result of positioning is shown in Table 1, where 70 % area of M-array is contaminated by a diagonal black mask as shown in Fig.5. The crosscorreloation function of Fig.5 is shown in Fig.6. By using this 70 % contaminated M-array, the positioning is carried out by use of out-of-focus condition. The process of positioning is shown in Table 1, where 9×9 crosscorrelation values in the vicinity of the peak is shown together with the correction $dx$ and $dy$. Note that $\Phi(5,5)$ point of the crosscorrelation value is the true peak of the crosscorrelation function. As is seen from Table 1, the correct positioning is performed even when 70 % area of M-array pattern is contaminated by noise.

## 7. Conclusion

The two-dimensional positioning system by use of M-array proposed by the authers in '88KACC is much improved by use of correlation of vague M-array. The vague M-array which is opticxally obtained with TV camera in out-of-focus condition essentially plays a role of added M-array without calculating the addition of M-array[2]. Therefore, by use of the vague M-array, the positioning process becomes much faster in case of added M-array. The actual proto-type positioning system is constructed and the performance is checked for various condition. The positioning speed is shown to be within 2 seconds in the second stage and after(precise positióning).

As a result, it is shown that even 70 % area of M-array pattern is contaminated by some noise, the positioning system works well. Therefore this method of 2D positioning is expected to be used widely in the field of various industries even in noisy environment.

## References


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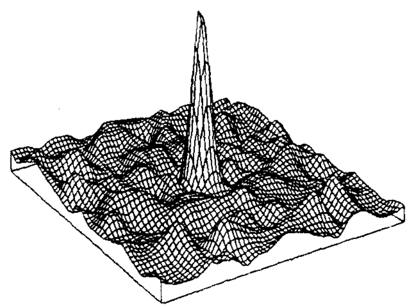

**Fig. 2** 2D Crosscorrelation function between the observed M-array and the reference.

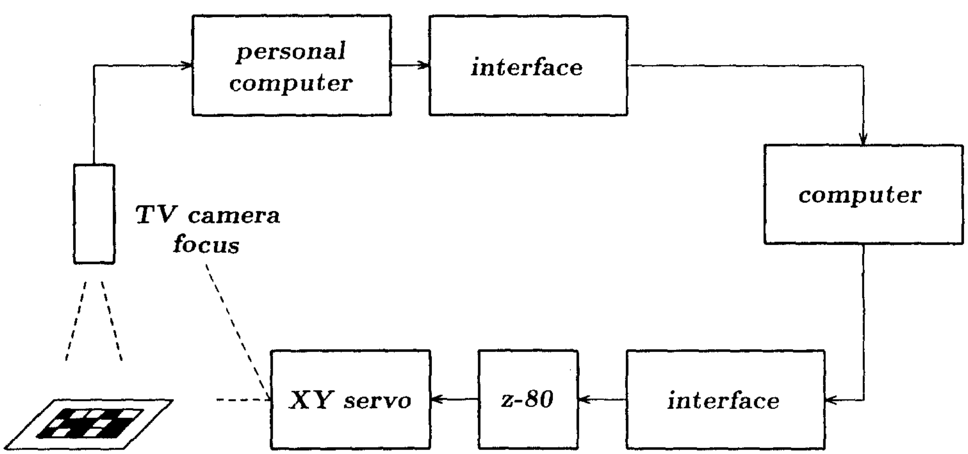


**Fig. 1** Schematic diagram of the 2D positioning system.

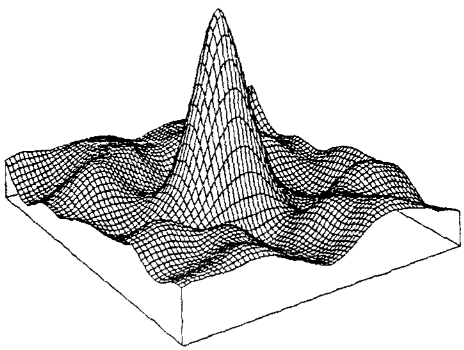

**Fig. 3** Effect of out-of-focus condition on cross-correlation function when the diameter of the added area is 11 times of that in focus.

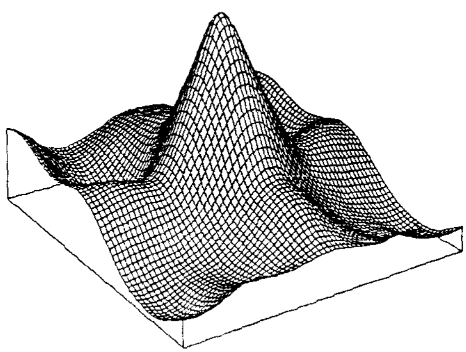

**Fig. 4** Effect of out-of-focus condition on cross-correlation function when the diameter of the added area is 17 times of that in focus.

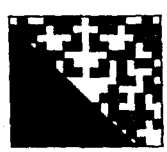

**Fig. 5** Contamination of M-array by a diagonal black mask.

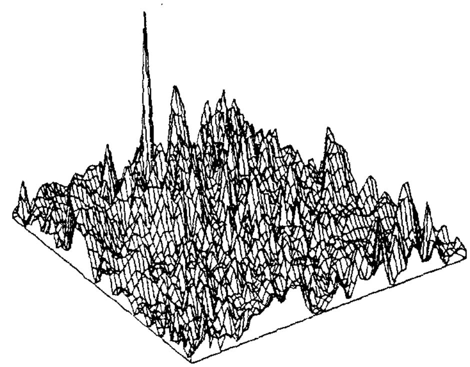

**Fig. 6** Crosscorrelation of contaminated M-array.

**Table 1** An example of experimental result on the process of positioning.

Stage Number 1

correction dx (X mm)=-14.0
correction dy (Y mm)= 4.0

Stage Number 2
CROSS-CORRELATION

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| -69 | -70 | -80 | -98 | -133 | -154 | -171 | -168 | -143 |
| -92 | -85 | -89 | -100 | -130 | -158 | -180 | -185 | -169 |
| -118 | -103 | -97 | -94 | -114 | -141 | -170 | -190 | -187 |
| -161 | -129 | -98 | -71 | -78 | -106 | -145 | -180 | -193 |
| -192 | -140 | -86 | -36 | -28 | -56 | -105 | -160 | -193 |
| -208 | -143 | -70 | -2 | 14 | -10 | -68 | -138 | -187 |
| -221 | -147 | -64 | 14 | 39 | 13 | -47 | -126 | -186 |
| -223 | -147 | -59 | 17 | 40 | 11 | -54 | -137 | -199 |
| -231 | -158 | -75 | -10 | 5 | -25 | -89 | -162 | -222 |

correction dx (X mm)= 0.0
correction dy (Y mm)= -1.5

Stage Number 3
CROSS-CORRELATION

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| -132 | -107 | -84 | -61 | -66 | -85 | -114 | -137 | -143 |
| -144 | -107 | -66 | -29 | -27 | -48 | -89 | -127 | -147 |
| -160 | -111 | -56 | -5 | 1 | -22 | -73 | -127 | -161 |
| -178 | -122 | -55 | 5 | 19 | -5 | -62 | -129 | -175 |
| -199 | -142 | -71 | -7 | 9 | -11 | -69 | -140 | -192 |
| -222 | -165 | -96 | -34 | -18 | -38 | -90 | -158 | -209 |
| -234 | -180 | -115 | -62 | -51 | -72 | -118 | -172 | -214 |
| -229 | -181 | -125 | -88 | -86 | -109 | -147 | -186 | -218 |
| -205 | -164 | -116 | -96 | -104 | -129 | -165 | -186 | -208 |

correction dx (X mm)= 0.0
correction dy (Y mm)= 0.5

Stage Number 4
CROSS-CORRELATION

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| -117 | -105 | -92 | -91 | -105 | -124 | -151 | -166 | -161 |
| -145 | -121 | -92 | -72 | -73 | -90 | -125 | -153 | -166 |
| -166 | -131 | -84 | -44 | -34 | -52 | -97 | -141 | -170 |
| -192 | -144 | -80 | -16 | 9 | -5 | -54 | -115 | -161 |
| -216 | -159 | -83 | -3 | 34 | 21 | -32 | -105 | -166 |
| -230 | -171 | -91 | -8 | 28 | 18 | -35 | -108 | -169 |
| -243 | -185 | -107 | -27 | 7 | -2 | -52 | -121 | -179 |
| -245 | -192 | -123 | -61 | -38 | -53 | -99 | -153 | -202 |
| -235 | -186 | -126 | -84 | -74 | -97 | -139 | -175 | -212 |

correction dx (X mm)= 0.0
correction dy (Y mm)= 0.0

total displacement (X)= 136.0
total displacement (Y)= 203.0