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ZOOMING FUNCTIONAL METHOD FOR POSITION MEASUREMENT IN ENCLOSING SIGNAL FIELD BASED ON CONCEPT OF PROGRESSIVE LEARNING MEASUREMENT SYSTEM

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Abstract A method for two-dimensional position measurement using an enclosing signal field has been studied and reported. The feature of this method is a zooming functional measurement by operating both the initial phase shift and the brightness ratio of the lighting function. An experimental system was developed and the experimental results on zooming effects are shown in this paper. This system is also an example of a "progressive learning measurement system."

Keywords Signal field, Local positioning system, Position measurement, Learning data

1. INTRODUCTION

We have been studying and have reported[1, 2] a position measurement method applying the concept of a "signal field," as a coordinate establishment system applicable to cooperative work by multiple robots operating in a factory. This method is based on the idea of an advanced active sensing system; it is also called an LPS(Local Positioning System)[1], and its the greatest feature is the "zooming functional measurement," which means that it includes both wide & low sensitivity and narrow & high sensitivity measurement with identical hardware construction.

Because this zooming functional measurement is also a feedback measuring system, it can be expressed as a "progressive learning measurement system[3]" by emphasizing the learning data.

In practice, **Fig. 1** shows the basic structure of the learning measurement system. It makes the most of the freedom of degree of measurement, and the measuring system works by changing only the operation parameters properly without changing the hardware construction, so that measurement can cope with a change in the environment, and the measurement range, speed, precision, and so on. In this figure, the greatest feature is that a feedback loop is contained in the system, and the measuring result of the previous step is used in the next step. In the case of this paper, the operation of a macro/micro-2-step measurement displays this function.

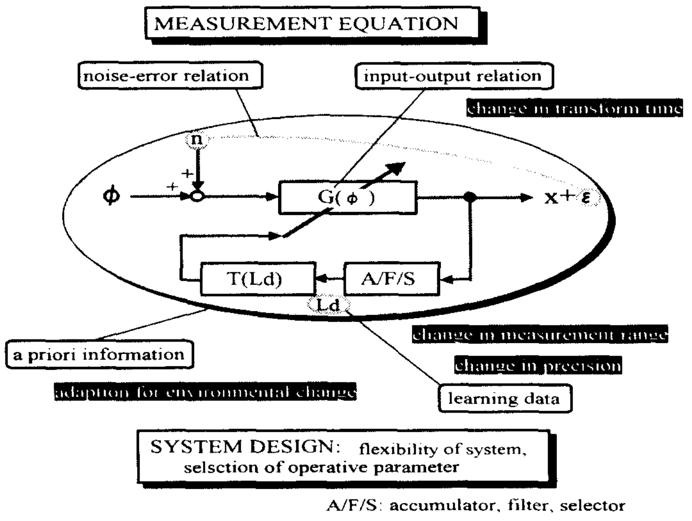


Fig. 1: Basic structure of progressive learning measurement system.

In the following paper, the principle of zooming measurement is shown using an enclosing signal field as an example of a progressive learning measurement system.

2. PRINCIPLE OF POSITION MEASUREMENT

2.1 Construction of Enclosing Signal Field

Consider the arrangement of four LED-arrays as shown in **Fig. 2**. LEDs-A, B, C and D are linear LED arrays, and they are located on each lattice of a square. The length of the lattice is 2a. Each face of an LED is directed toward the origin (O) of the coordinates. Points P_1, P_2 and P_3 are the positions of the photodetectors. The purpose of this measurement is to determine the coordinates of each detector. Each detector is capable of moving on a plane, which is called the *sensing plane*. The size of each detector is small enough to be regarded

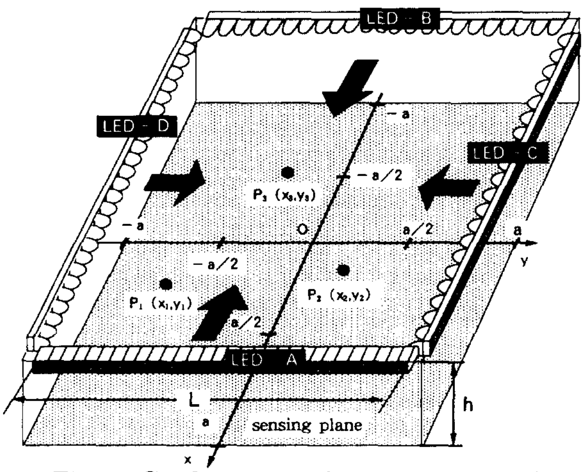


Fig. 2: Configuration of enclosing signal field.

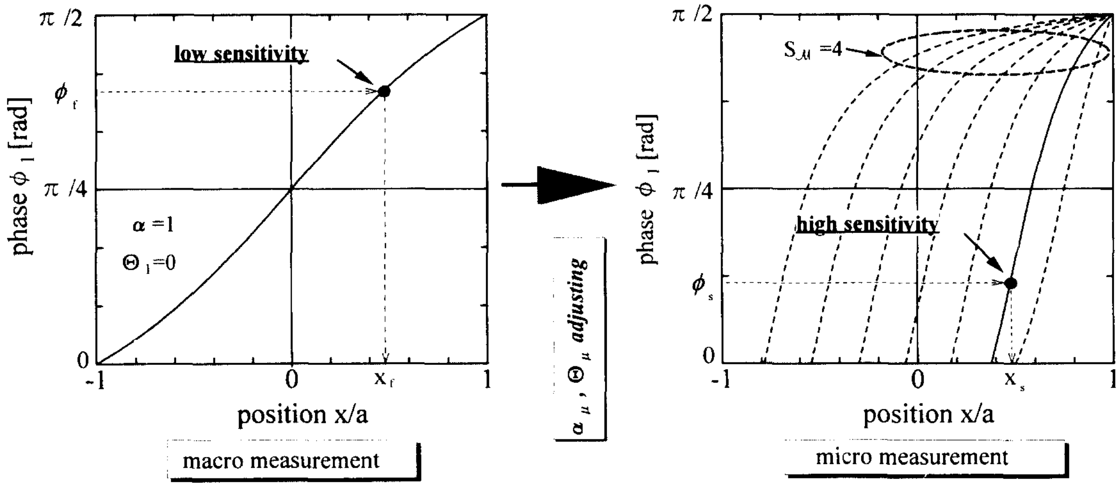


Fig. 3: Macro- and micro- measurement based on adjustment of both initial phase and brightness ratio.

as a pinpoint, and their directional sensitivity is isotropically uniform in all directions. The distance between the LED plane and the sensing plane is h.

Every LED light according to a sine wave with a specific amplitude and initial phase shift, that is, their lighting functions are as follows.

$$A : A(t) = \kappa_A \cos \omega_1 t \tag{1}$$

$$B : B(t) = \kappa_B \sin(\omega_1 t + \Theta_1) \tag{2}$$

$$C : C(t) = \kappa_C \cos \omega_2 t \tag{3}$$

$$D : D(t) = \kappa_D \sin(\omega_2 t + \Theta_2) \tag{4}$$

A special signal field is generated by the superposition of four kinds of signals in the inner space between the LED and sensing planes. This is the *enclosing signal field.* This signal field has the following properties. To simplify the problem, assuming that the length of an LED array (=L) is infinity (but the actual length of the lattice is still 2a), the light intensity propagates and decreases inversely with the distance between an LED array and a photodetector. Consequently, the signal, $P(t)$, obtained at any point, $P(x, y)$, is given by eq.(5).

$$\begin{aligned} P(t) = &\frac{\kappa_A \cos \omega_1 t}{\sqrt{(a-x)^2 + h^2}} + \frac{\kappa_B \sin(\omega_1 t + \Theta_1)}{\sqrt{(a+x)^2 + h^2}} \\ &+ \frac{\kappa_C \cos \omega_2 t}{\sqrt{(a-y)^2 + h^2}} + \frac{\kappa_D \sin(\omega_2 t + \Theta_2)}{\sqrt{(a+y)^2 + h^2}} \\ = &\Psi_1 \sin(\omega_1 t + \phi_1) + \Psi_2 \sin(\omega_2 t + \phi_2) \end{aligned} \tag{5}$$

Where ϕ_1 and ϕ_2 are presented as eq.(6) and (7).

$$\phi_1 = \tan^{-1}\left(\sqrt{\frac{(a+x)^2 + h^2}{(a-x)^2 + h^2}} \times \frac{\alpha}{\cos \Theta_1} + \tan \Theta_1\right) \tag{6}$$

$$\phi_2 = \tan^{-1}\left(\sqrt{\frac{(a+y)^2 + h^2}{(a-y)^2 + h^2}} \times \frac{\beta}{\cos \Theta_2} + \tan \Theta_2\right) \tag{7}$$

In eqs.(6) and (7), α and β are the luminance ratio of facing LEDs and are defined as follows.

$$\alpha = \frac{\kappa_A}{\kappa_B}, \qquad \beta = \frac{\kappa_C}{\kappa_D} \tag{8}$$

Eq.(5) shows that $P(t)$ is composed of two frequency components, ω_1 and ω_2, and each phase shift, ϕ_1 and ϕ_2, is expressed by eqs.(6) and (7), respectively. In eq.(5), a and h are constants determined by the morphology of the arrangement of these devices, while the luminance ratio, α and β, and the initial phase, Θ_1 and Θ_2, are variables capable of being adjusted, and we can intentionally control them. It is clear that in eqs. (6) and (7) the phase shifts, ϕ_1 and ϕ_2, are the functions of positions x, y, respectively.

It is important that the phase characteristic related to the position by manipulating both the initial phase shift Θ_1, Θ_2 and the brightness ratio α, β can be changed; the zooming functional measurement is carried out using this feature.

2.2 Zooming Functional Measurement

As shown in 2.1, a coordinate (x, y) can be determined if (ϕ_1, ϕ_2) at each point becomes known. In addition, the zooming functional measurement means that the measuring precision is changed by making the feature of the signal field by suitably manipulating both the brightness ratio and the initial phase shift.

Macro/micro-2-step measurement using this function is shown in **Fig. 3**. Macro-lighting ($\alpha = 1, \Theta_1 = 0$) is done at first, and an approximate position (x_f) is measured by this. Using this result, the initial phase shift and the brightness ratio are changed so that the measurement sensitivity may become the largest at x_f, and the position measurement with micro-lighting is done. At this time, both α_μ and Θ_μ are determined by the following eqs.(9),(10) using the result of the macro-measurement as a focusing point x_0[1]. In these equations, $S_{\mathcal{M}}$ is the setting sensitivity at the micro measurement.

$$\alpha_\mu = \sqrt{\frac{S_{\mathcal{M}}{}^2 (a - x_0)^2 + 1}{S_{\mathcal{M}}{}^2 (a + x_0)^2 + 1}} \tag{9}$$

$$\Theta_\mu = \sin^{-1} \frac{1 - S_{\mathcal{M}}{}^2(a^2 - x_0{}^2)}{\sqrt{\left(S_{\mathcal{M}}{}^2(a+x_0)^2+1\right)\left(S_{\mathcal{M}}{}^2(a-x_0)^2+1\right)}} \tag{10}$$

3. EXPERIMENTS

3.1 Experimental Flow

The process as described in 2.2 is shown in **Fig. 4** as a flow chart. First, the setting sensitivity $S_{\mathcal{M}}$ is input, and macro-measurement is done using macro-lighting. Coordinate (x_f, y_f) is determined from the phase (ϕ_{1f}, ϕ_{2f}). $\Theta_{1\mu}, \Theta_{2\mu}, \alpha, \beta$ are then calculated by eqs. (9),(10) so that (x_f, y_f) may become a focusing point. Using these parameters, micro-lighting is done for the micro-measurement.

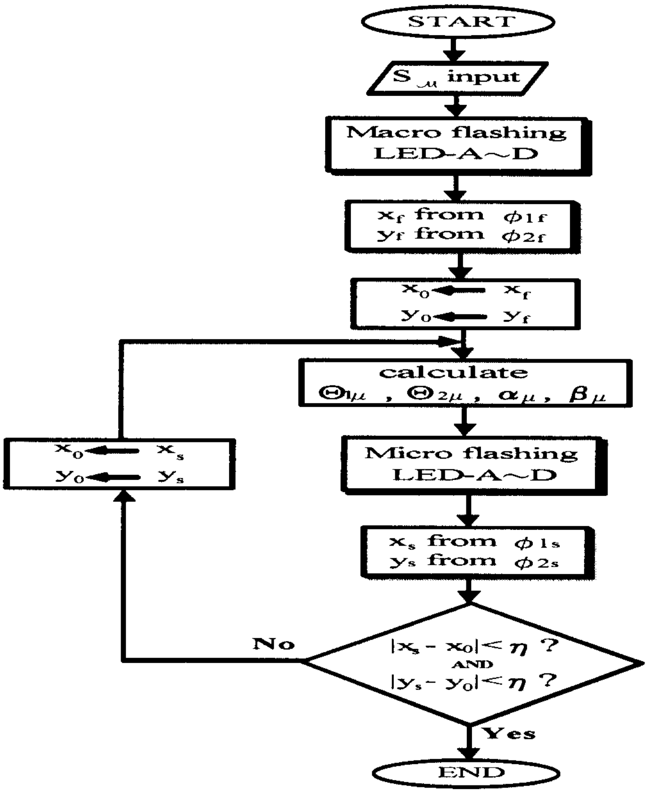


Fig. 4: Flowchart of two-dimensional zooming measurement.

3.2 Experimental Setup

Focusing points x_s and macro result x_0 do not always correspond to the micro measurement result. The micro-measurement is then repeated until the difference between x_s and x_0 is smaller than η which is set up in advance. $|x_s - x_0|$, $|y_s - y_0|$ were the parameters which showed the agreement degree of the focusing point and the maximum sensitivity point with this measuring, and η was experimentally determined to be 2 % of L.

A photograph of the experimental setup is shown in **Fig. 5**. A precise setting table with a $50\mu m$ step which had a stroke of about 700 mm with the (x,y) coordinate was designed and made for these experiments. Linear LED arrays are now used for facsimiles and photocopy machines, and the length of 320 mm was used for these

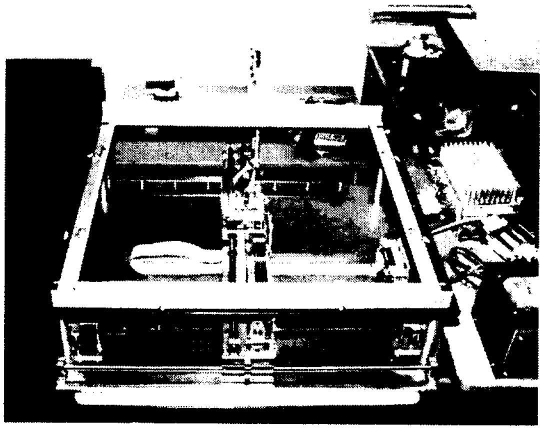
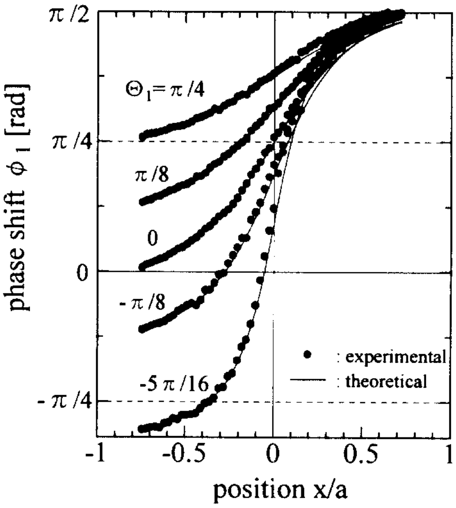
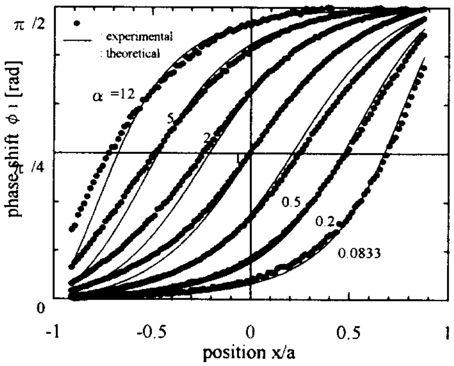


Fig. 5: Photograph of experimental system.

experiments. Eight LED arrays are mounted on the table, and a pair of LED arrays constitute the lattice of a square, in which the length 2a is 640mm. Lighting functions are given by the function generator, and the parameters α, β, Θ_1 and Θ_2 are all computer-controlled. The data for the brightness ratio and the initial phase shift are all given by 12-bit digital data. The frequen-



(a) Effects of initial phase Θ_1.



(b) Effects of brightness ratio α.

Fig. 6: Experimental results of fundamental effect of Θ_1 and α.

cies corresponding to ω_1 and ω_2 are 1 kHz and 2 kHz, respectively.

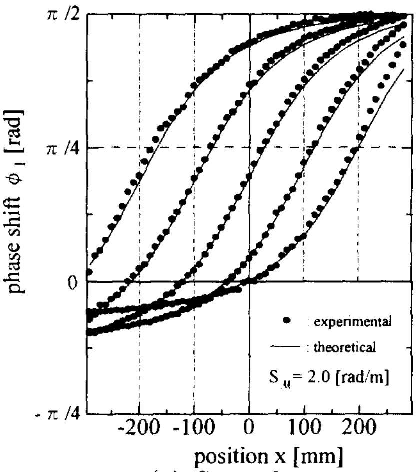
3.3 Experimental Results

The relations between the setting position and the observed phase relative to the change in the initial phase shift and the brightness ratio is shown in **Fig. 6**.

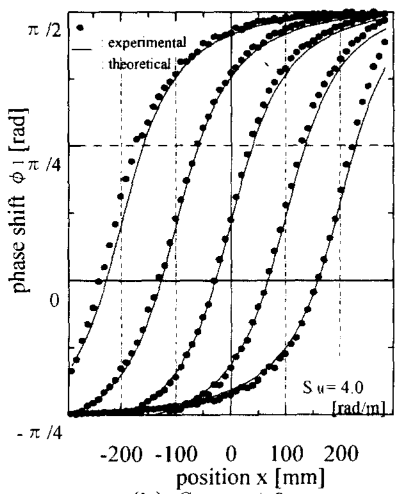
Fig. 6(a) shows the effect of the initial phase shift, and this is followed by shifting the initial phase shift to the negative side according to the theory, and the sensitivity around the origin increases.

Fig. 6(b) is the effect of the brightness ratio, and the point which becomes maximum sensitivity according to the theory is around $\alpha = 1$. The graph is then moved according to the change in α.

When the position of the focusing point is set to -200, -100, 0, 100, 200 mm, and Θ and α are determined by eqs. (10), (9), the position-phase characteristic curve is shown in **Fig. 7**. Fig. 7(a), (b) correspond to the setting sensitivity $S_{\mathcal{M}}$ 2.0, 4.0, respectively. These results revealed that the sensitivity curve changes in accordance with $S_{\mathcal{M}}$, and sensitivity becomes the largest around the focusing point.



(a) $S_{\mathcal{M}} = 2.0$.



(b) $S_{\mathcal{M}} = 4.0$.

Fig. 7: Experimental results of optimum characteristics curve where the zooming points are $-200, -100, 0, 100, 200[mm]$.

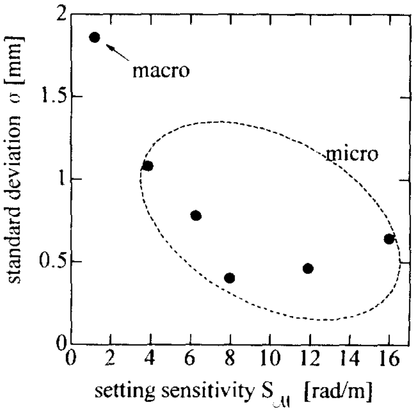


Fig. 8: Relationship between sensitivity $S_{\mathcal{M}}$ and standard deviation in error.

Finally, macro/micro-2-step measurement over the whole area ($640 \times 640mm$) was done according to the flow chart shown in Fig. 4. The relationship between the setting sensitivity and the standard deviation in the error is shown in **Fig. 8**. It is clear from this figure that the standard deviation in the error decreases according to the increase in setting sensitivity to 8.

4. CONCLUSIONS

A zooming functional measurement using an enclosing signal field is proposed and its effectiveness was examined. It was clear that on increasing the setting sensitivity of micro-measurement, the standard deviation in the error decreases. In other words, a measurement with high precision could be realized. This could be said to be an example of a progressive learning measurement system. The way to make effective use of learning data is the subject of a future study.

5. ACKNOWLEDGEMENT

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