A Simplified Teaching Method of a Playback-Type Industrial Robot

by

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The present study is devoted to the development of a simplified teaching method whereby the control data of the 3-dimensional operations of a playback-type industrial robot can be stored in a personal computer. The control data of the 3-dimensional operations are given using an instruction wand handled by an operator. The operator's task is only to track a desired robot path with the wand. The 3-dimensional position of the wand are measured by ultrasonic devices, the principle of which was developed for this study and is introduced in detail. In order to clarify the applicability of this method, experiments were performed with respect to a continuous-path teaching and a pick-and-place task teaching which are typical jobs of robot operators.

1. Intoduction

Recently in highly developed factories, robots are controlled by central computers which are located some distance away from the operator room. All commands to these robots are automatically planned and generated by the computer, and the operator's tasks are limited some special ones, e. g. maintainance or inspection. However, in many factories original playback-type robot systems, where operators specify all robot paths and every operation with a teaching box, are still used, as with handing or spot-welding machines. One of the reasons why these systems are still used in many factories is that playback-type robot systems are simple and stable operations can be maintained under most operating conditions. On the contrary, the performance of highly intelligent robots with some sensors is likely to be much influenced by the enviroment. For example, robot systems with vision sensors need special attention as to the lighting. If the lighting is not sufficient, the robots easily fail to identify the target object.

Although original playback-type robot systems with manual teaching provide us stable operations, teaching tasks with a teaching box require great skill and often several hours for each task. Moreover, these systems pose some physical risk to the operator.

In this paper a new teaching method is proposed, whereby all the desired robot paths are specified with the tip of an instruction wand which is handled by the operator. The operator's task is only to track the desired robot paths with the tip of the instruction wand and to push some buttons on the wand in order to send signals to a computer. Since this teaching method is considerably simple and easy, even an operator without skill can finish teaching in a short time. Furthermore, for safety this method enables operators to stop the robot completely during the teaching time.

In the proposed method, the most important features are three sets of ultrasonic devices measure 3-dimensional position of the instruction wand. Of course, there are other kinds of devices to measure

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the 3-dimensional position of an object. A mechanical multi-link system, which is similar to a robot arm, enables such measurements with high accuracy. However, its operation is not easy since the system is bulky and large in order to increase its rigidness. Optical 3-dimensional devices are also available[1][2]; however, they have some problems e. g. accuracy, cost and lighting. The advantages of using ultrasonic devices are that the resultant system becomes simpler and inexpensive and that special attention to lighting is not needed.

2. Teaching System

The proposed system is depicted in Fig. 1. This teaching system consists of an instruction wand

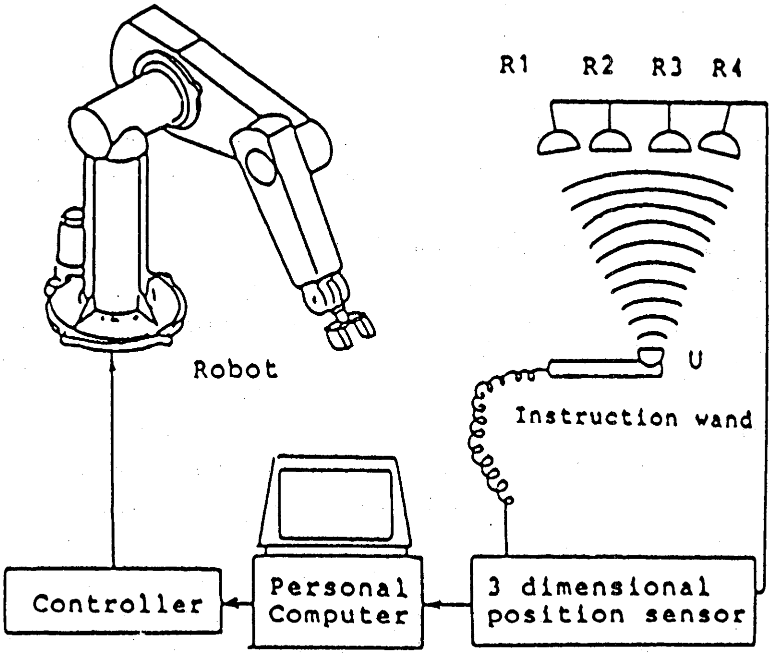

Fig. 1 Teaching system

whereby operations and 3-dimensional paths of a playback-type industrial robot are given, ultrasonic receivers $R_1 \sim R_4$ fixed above the working space, a 3-dimensional position sensor which determines the 3-dimensional position of the ultrasonic emitter on the instruction wand and a personal computer which stores all the operations and the robot paths given by the instruction wand. On the instruction wand an ultrasonic emitter U, whose emitting frequency is 40kHz, is mounted. An ultrasonic signal with a frequency of 40kHz is received by receivers R_1, R_2, R_3, and R_4. Distances between them are calculated by a principle introduced in the following section. Then the 3-dimensional position of the emitter U is immediately identified by a well-known principle of trignometrical survey. As can be noted easily, this system can not measure the posture of the wand. Hence, if the operator want to specify the posture of the robot hand, the operator has to move the wand to specify two or three points of desired robot posture. Of course, supplement of other emitters would enables measurement of the posture of the wand.

3. Principle of Distance Sensor

In order to idetify the 3-dimensional position of the instruction wand by the principle of trigonometrical survey, distances between the ultrasonic emitter and receivers have to be measured with high accuracy.

With respect to general ultrasonic distance sensing devices, a distance between the emitter and the receiver is determined by a traveling time of ultrasonic pulse waves between them[3]. However, there are some difficulties in obtaining an accurate value through air by the above method. The reason is that the emitter and the receiver can not have an ideal dynamic response, The inherent measurement error corresponds to the length of several ultrasonic waves.

In order to eanable a more accurate measurement, one new method is introduced here. Suppose ultrasonic waves with a frequency f_1 are emitted stationary, and the emitter E and the receiver R are placed at the distance L apart. L can be expresed by

$$L=(N+\frac{\phi_n}{2\pi})\frac{C}{f_1} \qquad (1)$$

where N is an integer, C is acoustic velocity and ϕ_n is the phase difference between emitted waves W_1 and received waves W_2.

On the righthand side of Eq.(1) it is clear that the phase difference ϕ_n can be measured with accuracy. It is important to note that a continuous measurement of ϕ_n also enables one to determine the variation of distance L. Therefore, if the initial value of the distance L between the emitter E and the receiver R or the initial value N on the righthand side term can be determined by some method, the absolute values of L can de determined at any subsequent instance.

One benefit of this method is that its accuracy is not affected by the dynamic response of the ultrasonic devices. Moreover, a measurement with a high sampling frequency is possible.

In the following, one method is proposed to give the initial value of L or N in Eq.(1). Consider that an emitter E and a receiver R are placed at a distance L apart, and the emitter is emitting ultrasonic waves with a frequency f_1, as is shown in Fig. 2.

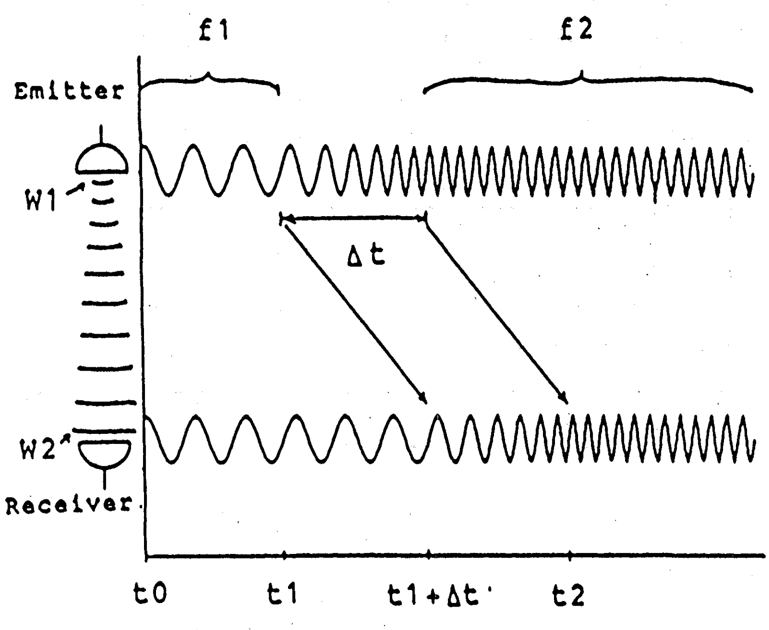

Fig. 2 Principle of measurement

Additionally, consider that emitting frequency is shifted from f_1 to f_2 at a specified period $[t_1, t_1+\Delta t]$ without any skewing of sinusoidal emitting waves W_1. Since the ultrasonic waves with a frequency f_2

reach the receiver at $t=t_1+L/C$, the number of waves W_1 emitted by E between the interval t_0 and t_2 is $f_1(t_1-t_0)+f_2(t_2-t_1)$ and that of waves received by R is $f_1(t_1+L/C-t_0)+f_2(t_2-t_1-L/C)$. Therefore, the difference D between the above two numbers becomes $(f_2-f_1)L/C$, which is in proportion to the distance L.

As a result, the distance can be determined by

$$L=D\frac{C}{f_2-f_1} \qquad (2)$$

If D is expressed by a sum of an integer number N_D and a decimal number $\phi/2\pi$ $(0\leqq\phi\leqq2\pi)$, Eq.(2) becomes

$$L=(N_D+\frac{\phi}{2\pi})\frac{C}{f_2-f_1} \qquad (3)$$

Eq. (3) implies that the increase of the difference f_2-f_1 gives a more accurate result. It is clear that it is possible to measure ϕ down to two decimal places. It should also be noted that the accuracy of this method is not affected by the dynamic response of the devices.

On determining the initial value of L by Eq. (3), it is not needed to get a completely accurate value. This measurement needs only to be accurate enough to determine N_D on the righthand side of Eq. (3), because the accurate value of ϕ_D in Eq. (1) can be obtained and is available to determine N_D. Considering that the phase difference ϕ_D in Eq. (1) is a periodic function with wave length C/f_1, it is derived that the allowable measurement error of L by Eq. (3) must de less than C/f_1. Fig. 3 shows how the frequency of ultrasonic wave emitted varies during the measurement period. In the first period of $[t_1, t_2]$ N is determined and the accurate value of L is determined by Eq. (1), It is clear that since continuous measurement of ϕ_D enables to determine the variation of L in the following period $[t_2, t_3,]$ the absolute value L is determined without frequency variation.

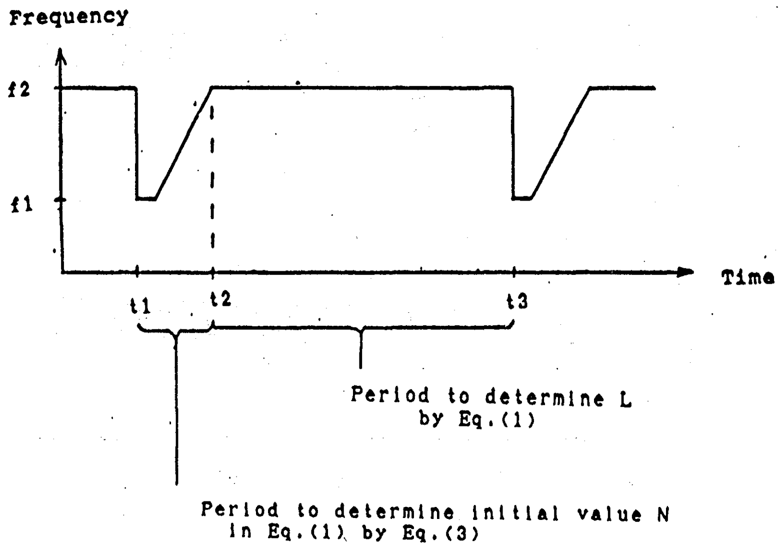

Fig. 3 Frequency variation

4. Determination of 3-Dimensional Position

In order to obtain an accurate 3-dimensional information about instruction wand, the positions of every ultrasonic receiver have to be established in advance. The system developed adopted a calibrating method, whereby operators have to track three points whose world coordinates are already known with the tip of the instruction wand.

Suppose, R_i is i-th ultrasonic receiver whose world coodinate is unknown and A, B, C are points whose world coodinates are already known as is shown in Fig. 4. By pointing A, B, C with the wand, the distance between the receiver R_1 and points A, B and C are measured.

Let the distances be L_a, L_b and L_c. Then the geometrical relation yields

$$\begin{aligned} &(x_i-L)^2+y_i^2+z_i^2=L_B^2, \\ &x_i^2+(y_i-L)^2+z_i^2=L_C^2, \qquad (4) \\ &x_i^2+y_i^2+z_i^2=L_A^2, \end{aligned}$$

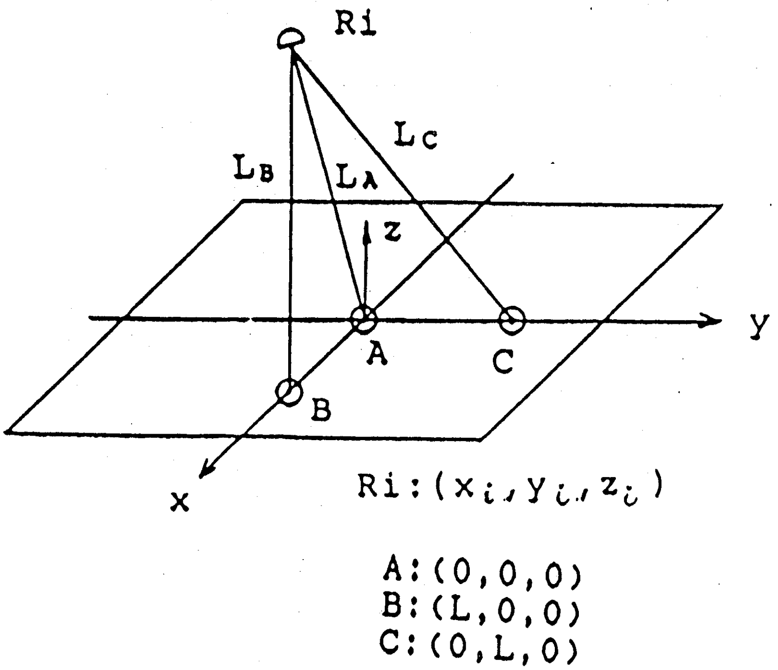

Fig. 4 Calibration of ultrasonic receiver

It is obvious that x_i, y_i, and z_i of Eq.(4) is obtained by

$$\begin{aligned} &x_i=(L_A^2-L_B^2+L^2)/2L, \\ &y_i=(L_A^2-L_C^2+L^2)/2L, \qquad (5) \\ &z_i=(L_A^2-x_i^2-y_i^2)^{\frac{1}{2}}, \end{aligned}$$

Once the coordinates of ultrasonic receivers are obtained, the principle of trigonometrical survey enables measurements of the 3-dimensional position of the instruction wand. Consider an ultrasonic emitter E placed at distances L_1, L_2 and L_3 apart from receivers R_1, R_2 and R_3 alternatively. Let the coodinate of the ultrasonic emitter E be shown Fig. 5.

The geometrical relation yields

$$(x_e-x_1)^2+(y_e-y_1)^2+(z_e-z_1)^2=L_1^2,$$
$$(x_e-x_2)^2+(y_e-y_2)^2+(z_e-z_2)^2=L_2^2, \qquad (6)$$
$$(x_e-x_3)^2+(y_e-y_3)^2+(z_e-z_3)^2=L_3^2,$$

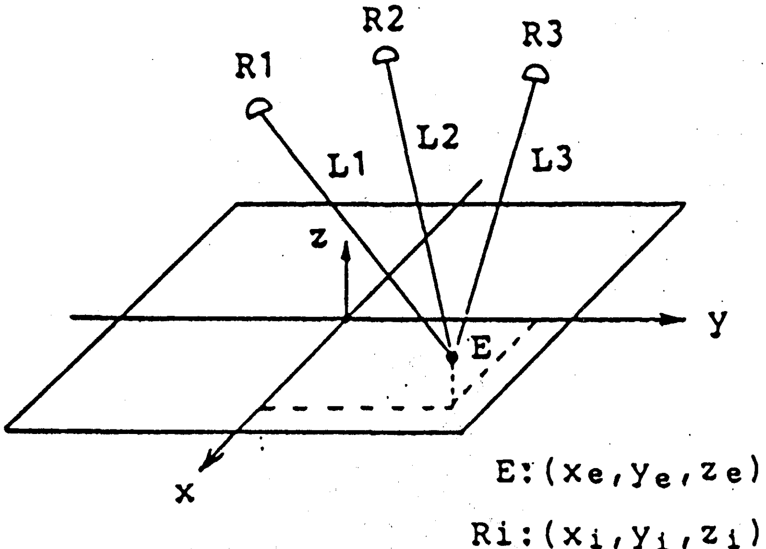

Fig. 5 Determination of 3-D position of ultrasonic emitter

Arranging the above expressions, the 3-dimensional coordinates of the emitter E are given by

$$x_e=ap+b+x_1,$$
$$y_e=cp+d+y_1, \qquad (7)$$
$$z_e=p+z_1,$$

where $\Delta x_i=x_1-x_i$, $\Delta y_i=y_i-y_1$, $\Delta z_i=z_i-z_1$ $(i=2,3)$

$$a=\frac{1}{g}(-\Delta z_2\,\Delta y_3+\Delta z_3\,\Delta y_2), \qquad b=\frac{1}{g}(k_2\,\Delta y_3-k_3\,\Delta y_2),$$
$$c=\frac{1}{g}(\Delta z_2\,\Delta x_3-\Delta z_3\,\Delta x_2), \qquad d=\frac{1}{g}(-k_2\,\Delta x_3+k_3\,\Delta x_2),$$
$$g=\Delta x_2\,\Delta y_3-\Delta y_2\,\Delta x_3, \qquad (8)$$
$$k_i=\frac{1}{2}(L_1^2-L_i^2+\Delta x_i^2+\Delta y_i^2+\Delta z_i^2) \qquad (i=1,2),$$

$$p=\frac{-(ab+cd)-\sqrt{(ab+cd)^2-(a^2+c^2+1)(b^2+d^2-L_1^2)}}{a^2+c^2+1}$$

While the information about the distance L_4 between the 4-th receiver and emitter E is not used to determine the 3-dimensional position of the emitter E, it is used to check the reliability of the solution determined by Eq. (8). Suppose the solution of Eq. (8) is reliable, then the value of e detemined by the following equation should be very small

$$e=L_4-((x_e-x_4)^2+(y_e-y_4)^2+(z_e-z_4)^2)^{\frac{1}{2}} \qquad (9)$$

If the above value becomes more than several milimeters, there should be some conflicts between the data obtained. Reasons of this conflicts may be the ultrasonic wave emitted is blocked with some obstacles, sometimes operator's body. Also unfavorable reflected ultrasonic wave or misarrangement of the ultrasonic receivers and emitter many sometimes cause an excess value of e in Eq. (9).

Therefore, if the computer detects the excess value of e in Eq. (9), the 3-dimensional position data measured are omitted and a trial to obtain a reliable data are repeated.

Note that the small value of e in Eq. (9) does not necessarily assure the reliability of the data obtained. In some special cases the value of e may be less than 1.0mm, while the data are not reliable.

5. Experimental Results

A series of measurement were made in order to test the applicability of the teaching system developed. Ultrasonic receivers were arranged 750mm above the horizontal base surface to form an regular triangle with a side length of 500mm. The playback-type robot used had six freedoms with D. C. motors (PUMA 560).

In the case of the continuous-path teaching, an operator simulated the movement of the pen which drew some letters with the instruction wand. All the movements of the wand were measured and stored in a personal computer. After that, the playback-type robot was controlled by the computer.

Fig. 6. indicate one result, where the number of teaching points was 280 and teaching time spent was 70 seconds.

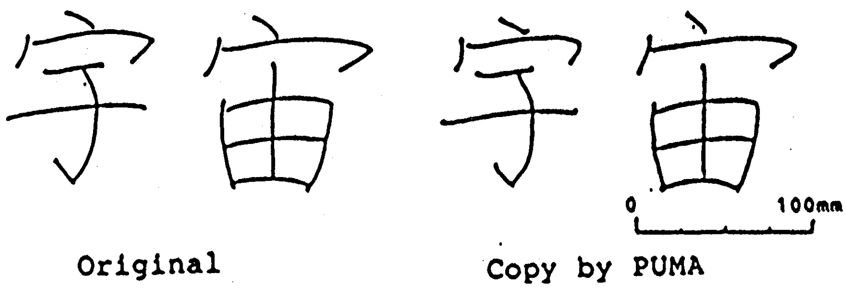

Fig. 6 Simulated Result on Graphic Display

Another experiment was to teach the robot a pick-and-place task. At the beginning. nine nuts were in a box at random. The best positions and orientations to grasp the nuts were instructed by an operator with the wand. Furthermore, every command as to place every nut were also given. Then, the computer automatically generated the paths and the operations of the robot. After confirmation of the paths and the operations on the T.V. monitor, the robot started to work. In this experiment 89 seconds were spent to finish teaching.

In the above experiments measurable volume on the base surface was 500mm in height, 600mm in width and 600mm in length, where the maximum error was less than 2.0mm.

6. Conclusions

A simplified method whereby the control data of the 3-dimensional operations of a playback-type industrial robot can be stored in a personal computer has been developed. The teaching task of the robot is achieved by using an instruction wand which is handled by an operator. The results of experiments show the practical applicability of this method. However, it is clear that its application to high precision work is somewhat limited because of its less than complete accuracy.

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