

SIMPLIFIED TEACHING OF A PLAYBACK-TYPE INDUSTRIAL ROBOT USING ULTRASONIC DEVICES

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Abstract: 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. Introduction

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. maintenance 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 handling or spot-welding machines in many factories. One of the reasons why these systems are still used is that playback-type robot systems are simple and stable operations that can be maintained under most operating conditions. On the contrary, the performance of highly intelligent robots with some sensors is much influenced by the environment. 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 object.

Although 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 which measure 3-dimensional position of the instruction wand. Of course, there are other kinds of devices to measure the 3-dimensional position of an object. A mechanical multi-body system, which is similar to a robot arm, enables such measurement with high accuracy. However, its operation is not easy since the system is bulky and large in order to increase its rigidity. 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.

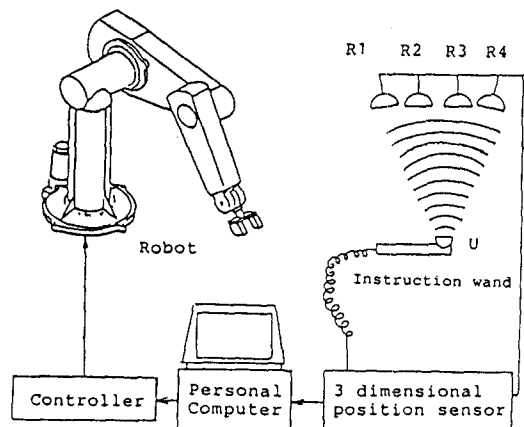
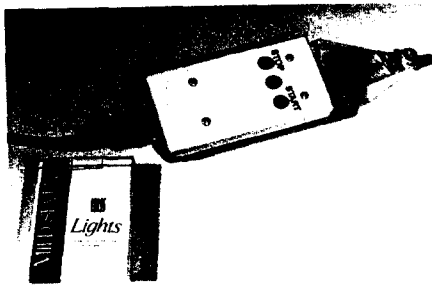


Fig.1 Teaching system

This teaching system consists of an instruction wand whereby operations and 3-dimensional paths of a playback-type industrial robot are given, ultrasonic receivers R1~R4 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 R1,R2,R3 and R4. 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 wellknown principle of trigonometrical 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.

Details of this instruction wand can be seen in Pic.1, where an ultrasonic emitter U and three buttons can be seen. Three buttons on the wand are used to send command signals to a personal computer. Those commands are to close or to open mechanical fingers mounted on the tip of the robot arm, to start or to stop storing the 3-dimensional positions of the wand into memory with 10Hz sampling frequency.



Pic.1 Instruction wand

3. Principle of Distance Sensor

In order to identify the 3-dimensional position of the instruction wand by the principle of trigonometrical survey, distances between 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 enable 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 expressed by

$$L = \left(N + \frac{\phi_0}{2\pi} \right) \frac{C}{f_1} \quad (1)$$

where N is a integer, c is acoustic velocity and ϕ_0 is the phase difference between emitted waves W1 and received waves W2.

On the righthand side of Eq.(1) it is clear that the phase difference ϕ_0 can be measured with accuracy. It is important to note that a continuous measurement of ϕ_0 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 be 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, 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.

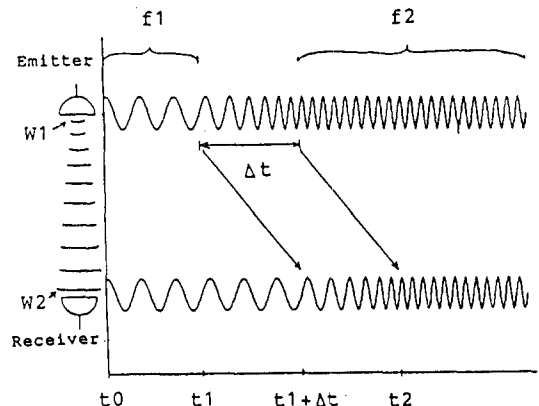


Fig.2 Principle of measurement

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

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

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

$$L = \left(N_0 + \frac{\phi}{2\pi} \right) \frac{C}{f_2 - f_1} \quad (3)$$

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 be accurate enough to determine N on the righthand side of Eq.(1), because the accurate value of ϕ in Eq.(1) can be obtained and is available to determine N . Considering the phase difference ϕ_0 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 be less than c/f_1 . Fig.3 shows how the frequency of ultrasonic 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_0 enable to determine the variation of L , in the following period $[t_2, t_3]$ the absolute value L is determined without frequency variation.

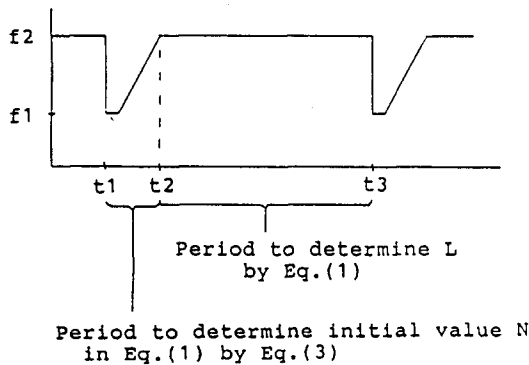


Fig.3 Frequency variation

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 coordinate are already known with the tip of the instruction wand.

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

Let the distances be L_A, L_B and L_C . Then the geometrical relation yields

$$\begin{aligned} (x_{pi} - L)^2 + y_{pi}^2 + z_{pi}^2 &= L_B^2, \\ x_{pi}^2 + (y_{pi} - L)^2 + z_{pi}^2 &= L_C^2, \\ x_{pi}^2 + y_{pi}^2 + z_{pi}^2 &= L_A^2. \end{aligned} \quad (4)$$

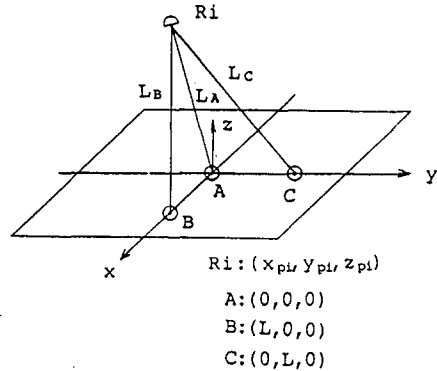


Fig.4 Calibration of ultrasonic receiver

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

$$\begin{aligned} x_{pi} &= (L_A^2 - L_B^2 + L_C^2) / 2L, \\ y_{pi} &= (L_A^2 - L_C^2 + L_B^2) / 2L, \\ z_{pi} &= (L_A^2 - x_{pi}^2 - y_{pi}^2)^{1/2}. \end{aligned} \quad (5)$$

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 L1, L2 and L3 apart from receivers R1, R2 and R3 alternatively. Let the coordinate of the ultrasonic emitter E be shown in Fig.5. The geometrical relation yields

$$\begin{aligned} (x_e - x_1)^2 + (y_e - y_1)^2 + (z_e - z_1)^2 &= L_1^2, \\ (x_e - x_2)^2 + (y_e - y_2)^2 + (z_e - z_2)^2 &= L_2^2, \\ (x_e - x_3)^2 + (y_e - y_3)^2 + (z_e - z_3)^2 &= L_3^2. \end{aligned} \quad (6)$$

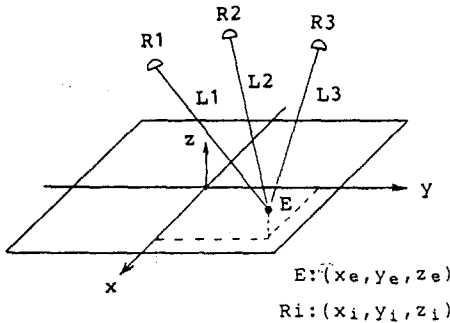


Fig.5 Determination of 3-D position of ultrasonic emitter

Arranging the above expressions the 3-dimensional coordinate of the emitter E is given by

$$\begin{aligned} x_e &= ap + b + x_1, \\ y_e &= cp + d + y_1, \\ z_e &= p + z_1 \end{aligned} \quad (7)$$

where $\Delta x_i = x_i - x_1, \Delta y_i = y_i - y_1, \Delta z_i = z_i - z_1$ ($i=1,2$)

$$\begin{aligned} a &= \frac{1}{g}(-\Delta z_2 \Delta y_3 + \Delta z_3 \Delta y_2), \\ b &= \frac{1}{g}(k_2 \Delta y_3 - k_3 \Delta y_2), \\ c &= \frac{1}{g}(\Delta z_2 \Delta x_3 - \Delta z_3 \Delta x_2), \\ d &= \frac{1}{g}(-k_2 \Delta x_3 + k_3 \Delta x_2), \\ g &= \Delta x_2 \Delta y_3 - \Delta y_2 \Delta x_3, \\ k_i &= \frac{1}{2}(L_i^2 - L_1^2 + \Delta x_i^2 + \Delta y_i^2 + \Delta z_i^2) \quad (i=1,2), \\ p &= \frac{-(ab+cd) - \sqrt{(ab+cd)^2 - (a^2+c^2+1)(b^2+d^2-L_1^2)}}{a^2+c^2+1}. \end{aligned} \quad (8)$$

While the information about the distance L4 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 determined by the following equation should be very small

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

If the above value becomes more than several millimeters, 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 and misarrangement of the ultrasonic receivers and emitter 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 the value of e may be less than 1.0 mm, while the data are not reliable.

A flow chart of teaching procedure of our system is shown in Fig.6.

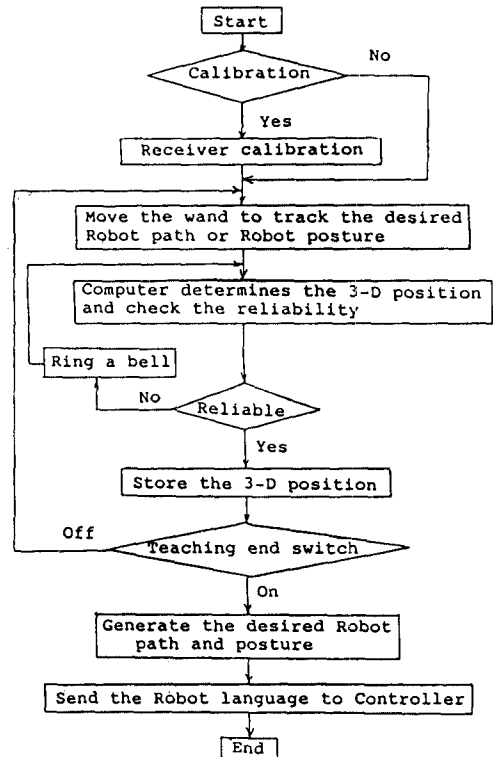


Fig.6 Flow chart of measurement

5. Experimental Results

Measurement Test

A series of measurement were made in order to test the accuracy 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. One result is shown in Fig.7, where an operator moved the instruction wand to track an regular square with a side length 200mm on the base surface. Circles with a radius 2.0mm are plotted at every points which were measured. The fact that every circle joins a side of regular square means the maximum measurement error was less than 2.0mm. With respect to the accuracy of the vertical direction, the maximum measurement error was less than 1.0mm. 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.

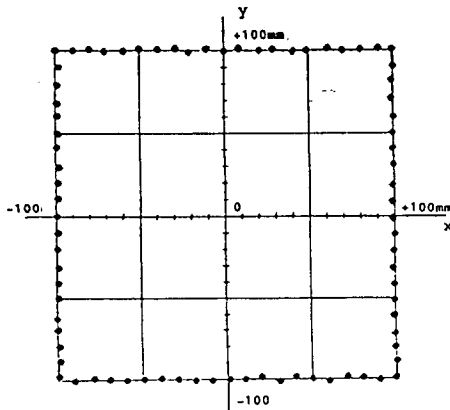


Fig.7 Positions of tip of wand

Teaching Test

In order to test the applicability of the teaching system developed, an playback-type industrial robot was actually driven. The playback-type robot used had six freedoms with D.C. motors.

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.8 and Pic.2 indicate one result, where the number of teaching points was 280 and teaching time spent was 70 seconds.

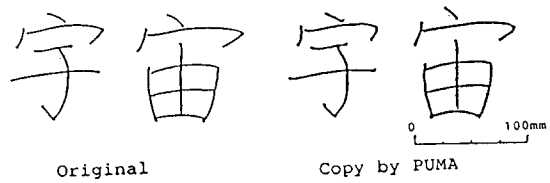
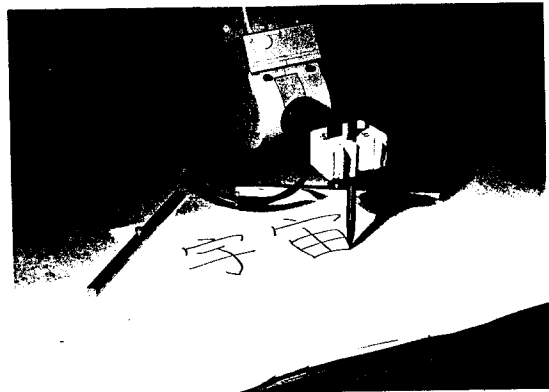


Fig.8 Example of playback



Pic.2 Robot drawing letters

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 80 seconds were spent to finish teaching.

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.

References

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