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# Robot Motion Regeneration based on Independent Arm Control System Design Method

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**Abstract:** In robot industries, the request to obtain a high efficiency and accurately controlled electric actuator has been growing. Nevertheless, the effectiveness of electric actuators is significantly affected by the presence of factors such as nonlinearity, uncertain disturbance and unknown dynamics. Therefore, it makes difficult to derive an exact mathematical model of the controlled system. In this paper, a new method for easily recognizing and regenerating robot motions used in small size industries such as painting and welding parts is proposed. Instead of modeling the entire dynamic motion of the robot system, this method is based on the procedure of modeling and controller design for every arm individually. The proposed method does not require complex model and control system such that it gives easy working process to the small size industries. Based on this fact, in this research, the model and PID controller for every arm of the 3 DOF robot system are obtained separately. Some experimental results are implemented to validate the effectiveness of the proposed method.

**Key words :** Robot, Painting and welding, Recognition, Regeneration, PID control

## 1. Introduction

Electric actuators play acrucialrole in automatic systems. In recent decades, automatic technology has been applied increasingly in rehabilitation applications such as painting and welding work. Nowadays, robotic welders and painters are used widely because of the capability of providing impeccable repeatability and high welding quality on the desired trajectory. The desired trajectory control performance may be made by small teaching robot,1) joystick,2) teaching pendant3) or teaching by the operator.4) Overall, robotic manipulators are nonlinear multi-input multi-output systems having to face various uncertainties such as pay load parameter, internal friction and external disturbance.5-6) In addition, they generally works in gravitational fields where gravity force is the major cause of positioning error in set-point control.7)

The authors applied a motion regeneration technique to the 3DOF manipulator.8-9) In this study, the manipulator is only moving on the plane without considering gravity force. Various techniques have been developed for position control of robot systems to regenerate the desired route accurately. In the industry applications, PID and advanced PID approaches are well known technique.10-12) Generally, PID gains were derive dusing many methods such as

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genetic algorithm and fuzzy technique, etc. And the nonlinear controllers such as adaptive control are also set up in this field.[3-4] However, these approaches require an exact model or on-line model identification. In this paper, a method for easily recognizing and regenerating robot motion is studied on the three degree-of-freedom robot system. To obtain the transfer function which represents dynamic motion of an arm, the identification process using step response is introduced. Next, the control lersare designed based on PID control algorithm. To regenerate target route exactly, the operator moves the end-effector of robot to the specified positions and orientations, and the route data of each arm are stored in the memory. These data are used as the reference signals for controllers. Finally, the effectiveness of the proposed method is successfully investigated by experimental results. The rest of this study is organized as followings. In Section 2 presents the mathematical model identification process, and Section 3, the controller is derived. In Section 4 shows the experiment results are shown.

## 2. Identifying Mathematical Model

As well known, to design the control system for a specified system, it is necessary to have the mathematical model which reflects the dynamic characteristics of the system. For many researchers in the field of robotics, to obtain the mathematical model of the robot system, they usually apply the Newton – Euler equations of motion, the Lagrangian formulation of motion or identification process. However, the method by using either the Newton – Euler method or the Lagrange is not a realistic alternative, because it is extremely difficult to measure mass, inertia tensor and physical properties of the robot system. Furthermore, the effect caused by friction is significantly complicated to be modeled exactly. It is obvious that the identification process using position and either torque or force data by collecting from experiment is a difficult mission to obtain the total robot dynamics.[15-16]

To overcome these difficult issues, in this study, we present an accessible identification method to attain the model of arms on a robot system. Due to instability of open-loop response, the closed-loop system with P controller is introduced to get the stable response as illustrated in Fig. 1.

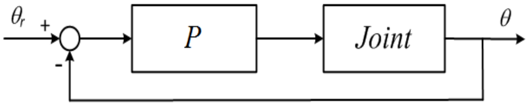

Fig. 1 Closed-loop system for obtaining model

To obtain the model which describes the motion dynamics of an arm, the authors use the step response of the closed-loop system. Among many step responses of the arm with respect to different reference values, the one sample is chosen to determine the model by considering operating range. This is treated as modeling process and highly depends on the operating range of the arm. Therefore, the order of the closed-loop transfer function $G_c(s)$ is established by choosing representative response. As well known, a system which may have system order higher than second can be approximated to the second order model. In this study, the second order model is chosen to characterize all responses of the closed-loop system. The two critical parameters, damping ratio $\xi$ and undamped natural frequency $\omega_n$ of the second-order system are calculated according to Percent overshoot $POT$, Steady-state error $e_{ss}$ and Settling time $t_s$ which are well known facts. For easy understanding, parameters of step response of the second order model are illustrated in Fig. 2.

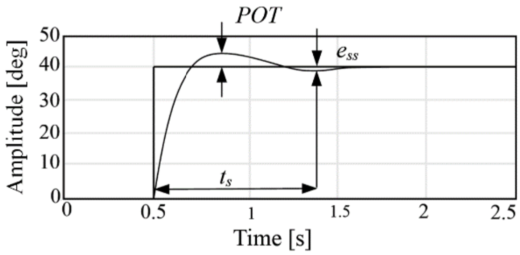

Fig. 2 Step response of the second order model

As a result, the closed-loop transfer function $G_c(s)$ with second-order is established as follows:

$$G_c(s) = \frac{PG(s)}{1+PG(s)} = \frac{\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2} \qquad (1)$$

$$G(s) = \frac{\omega_n^2}{P(s^2+2\xi\omega_n s)} \qquad (2)$$

$K = \omega_n^2 / P$ and $a = 2\xi\omega_n$. Consequently, the open-loop transfer function has the general form:

$$G(s) = \frac{K}{s(s+a)} \qquad (3)$$

For comprehensible illustration, the modeling procedure is demonstrated in Fig. 3.

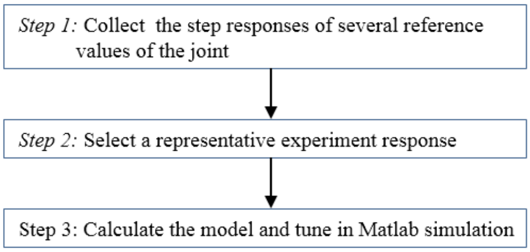

Fig. 3 Flowchart for modeling procedure

## 3. Controller Design

In this research, the authors design controllers based on PID control algorithm.

There are many approaches to design PID controller such as pole placement method, experimental method andso on. In this study, the controllers are calculated based on pole placement method for achieving desirable control performance.

In the PID control framework, the controller can be set as follows:

$$G_{PID}(s) = \left(K_P + \frac{K_I}{s} + K_D s\right) \qquad (4)$$

The characteristic equation of closed-loop system ofarm is:

$$1+G_{PID}(s)G(s) = 1+\left(K_P + \frac{K_I}{s} + K_D s\right)\left(\frac{K}{s^2+sa}\right)$$

$$= s^3 + s^2(a+K_D K) + s(KK_p) + KK_I \qquad (5)$$

On the other hand, we define the desired characteristic equation as follows:

$$(s+b)(s^2+2\xi_d\omega_{nd}s+\omega_{nd}^2) \qquad (6)$$

For the purpose of having no effect on the transient response of the system, the parameter $b$ should beselected 10 times greater than the magnitude of the real part of the pair of dominant complex poles from imaginary axis in the left-half $s$-plane. Equating equation (5) with (6), then parameters of PID controller are calculated according to equation (7):

$$K_I = \frac{b\omega_{nd}^2}{K}, K_P = \frac{2\xi_d\omega_{nd}+\omega_{nd}^2}{K}, K_D = \frac{2\xi_d\omega_{nd}+b-a}{K} \qquad (7)$$

## 4. Experiment

### 4.1 Experimental setup

In this section, the performance of the proposed approach has been verified through real-time experiments. For this purpose, an experimental system was built as depicted in Fig. 4.

The robot system employed in experimental phase is assembled by 3arms, named 3DOF system. To control robot arm motions, the controllers are programmed by applying Lab VIEW Programming Language 2009. The hardware configurations for digital control includes the acquisition card NI PXIe-6363 with a 4-channel 16-bit 1.25MS/s A/D converter and 4 counters 32-bit installed on the PXI express-Bus of platform NI PXIe-8115 embedded controller. The detailed specifications of the system components are summarized in Table 1, whereas the real apparatus is displayed in Fig. 5.

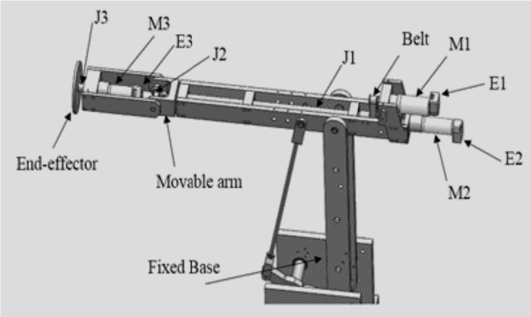

Fig. 4 Experimental configuration

## 4.2 Parameter identification

As mentioned previously, in this study, all models for robot arms are obtained experimentally. To identify parameter of thearm model, the closed-loop system with P controller is introduced in the experiment as shown in Fig. 1. The step responses for each arm are obtained and shown in Figs. 6~8 in which the set points are given from 5 to 50 degree with 5-degree deviation. The proportional gains for arms 1, 2, 3 are $P_1$ =0.06, $P_2$=0.095, $P_3$=0.165, respectively.

Table 1 Specifications of experimental components

| Items | 1st Arm | 2nd Arm | 3rd Arm |
|---|---|---|---|
| Motor | Maxon | Maxon | Maxon |
| Voltage [V] | 48 | 48 | 48 |
| Stall current [A] | 1.84 | 1.96 | 1.47 |
| Max. speed [rpm] | 12000 | 12000 | 5500 |
| Power [W] | 90 | 60 | 10 |
| Reduction | 51 | 51 | 33 |
| Encoder [p/r] | 500 | 500 | 500 |

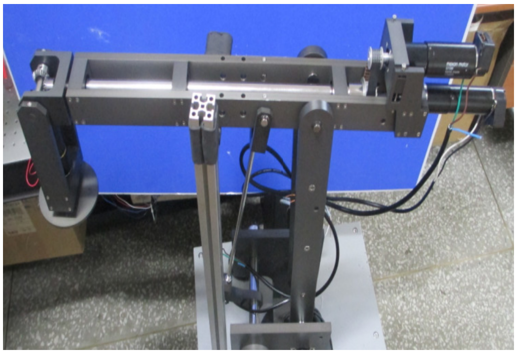

Fig. 5 Photograph of the experimental apparatus

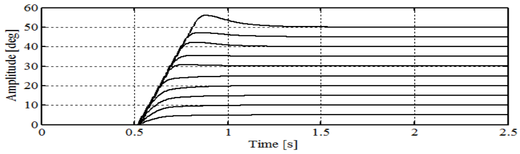

Fig. 6 Step responses of the 1st armat different setpoints

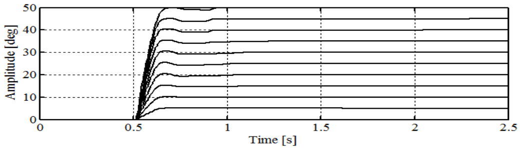

Fig. 7 Step responses of the2ndarmat different set points

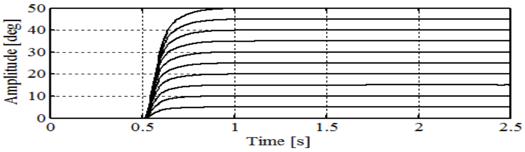

Fig. 8 Step responses of the 3rd armat different set points

As described in Section 2, to calculate the model of arm, the authors chose one of step responses. In our system, the permissible operating range of the first and third arm is ±180 degree, whereas that of the second armis from 0 to 210 degree. However, they are operated mainly in the range of ±60 degree, from 0 to 50 degree and ±60 degree with respect to the first, second and third arm. Consequently, we selected the step response at 30 degree as the representative response of the first, and third arm meanwhile the representative response of the secondarm is response at 25 degree to obtain the mathematical model. Then, the undamped natural frequency and damping ratio are calculated from these responses and transfer functions of arms are built and simulated in Matlab/Simulink. This needs several tuning times to fit simulated results as close as possible to experimental responses. Figs. 9~11 display the results for the process. Hence, the transfer function for each arm is obtained as follows:

$$G_1(s)=\frac{189}{s(s+24)},\ G_2(s)=\frac{569}{s(s+36)},$$
$$G_3(s)=\frac{74}{s(s+14)} \tag{8}$$

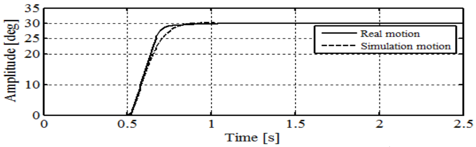

Fig. 9 Simulated and real motion of the 1st arm at $30^0$

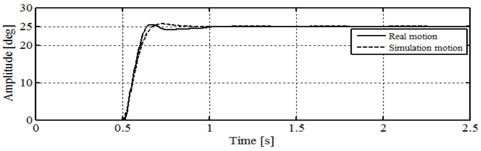

Fig. 10 Simulated and real motion of the 2nd arm at $25^0$

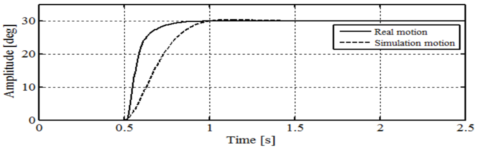

Fig. 11 Simulated and real motion of the 3rd arm at $30^0$

## 4.3 Controller design

The parameters of PID controllers are calculated according to Eq. (7) based on the transfer functions obtained in Eq. (8) with the desired performances of the closed-loop system *POT*=5%, settling time $t_s$=0.12s and steady-state error =5%. Then, controllers are simulated and tuned in experimentation to attain the best performance. Finally, the PID gains are chosen as follows:

$$K_{P1}=0.184, K_{I1}=0, K_{D1}=3.4\times10^{-5}$$
$$K_{P2}=0.1303, K_{I2}=0, K_{D2}=1.33\times10^{-5}$$
$$K_{P3}=0.474, K_{I3}=0.0322, K_{D3}=8.6\times10^{-5} \tag{9}$$

## 4.4 Experimental result

To regenerate desired trajectory, the operator moves the end-effector of robot to the specified positions and orientations, and the route data of each arm are stored in the memory. These data are used as the reference signals for controllers. Figs. 12~14 show the control performances for regenerated motion, Table 2 shows the root-mean-square error (RMS).

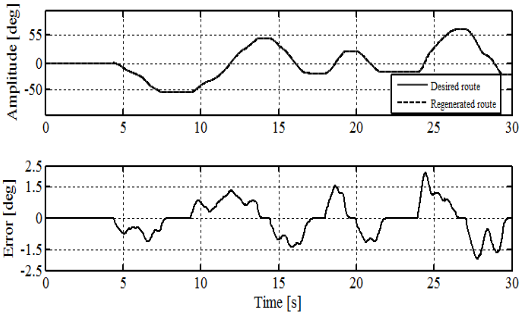

Fig. 12 Regenerated motion and error of the 1st arm

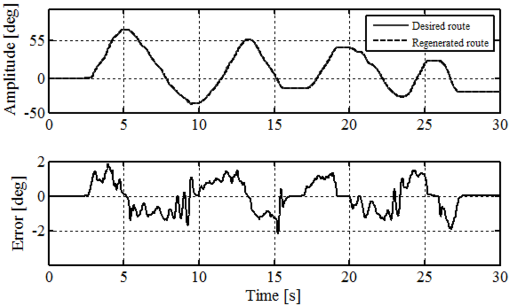

Fig. 13 Regenerated motion and error of the 2nd arm

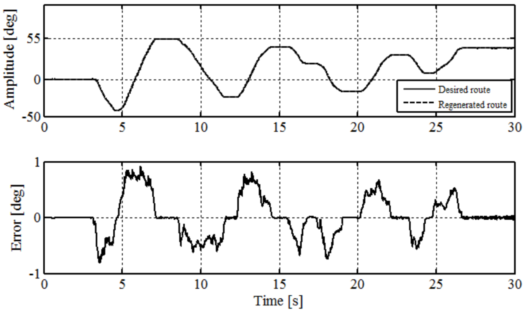

Fig. 14 Regenerated motion and error of the 3rd arm

Table 2 RMS error [deg]

| Arm | 1stArm | 2ndArm | 3rdArm |
|---|---|---|---|
| RMS Error | 0.81 | 0.92 | 0.34 |

## 5. Conclusion

This research introduced a simple method to model and design controller for regenerating motion of a robot system made by the operator. The mathematical model and the PID controller of the arm were calculated independently by considering small scale industries. In the small scale working places, few professional robot engineers are there.

From the experimental results, it is clear that the proposed strategy is simple, can achieve good performance with acceptable error. Moreover, it can be concluded that there no need to build the entire dynamic equations which are significantly complicated to be obtained and design the controller for a MIMO system. For further works, the modern controllers such as robust, adaptive and sliding mode must be deployed to the system to deal with variation of parameters as well as disturbances.

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## References

1. C. P. Hung and W. G. Liu, 2012,"Intuitive embedded teaching system design for multi-jointed robots", International Journal of Advanced Robotic Systems, Vol. 9, 34:2012.
2. R. Ikeura, and H. Inooka, 1994, "Manual control approach to the teaching of a robot task", IEEE Transaction son Systems, Man and Cybernetics, Vol. 24, No. 9, pp.1339-136.
3. S. Yong, Y. Huang, R. Chiba, T. Arai, T. Ueyama and J. Ota, 2013, "Teaching-playback robot 4manipulator system in consideration of singularities", IEEE International Conference on Advanced Intelligent Mechatronics, pp. 1-6.
4. Y. Maeda and T. Nakamura, 2015, "View-based teaching and playback for robotic manipulation", ROBOMECH Journal, Springer, pp. 1-12.
5. A. R. N. Ravari and H. D. Taghirad, 2008, "A novel hybrid Fuzzy-PID controller for tracking control of robot manipulators", IEEE International Conference on Robotics and Biomimetics, pp. 1625-1630.
6. T. J. Tarn, A. K. Bejczy, X. Yun and Z. Li, 1991, "Effect of motor dynamics on nonlinear feedback robot arm control", IEEE Transactions On Robotics and Automation, Vol. 7, No.1, pp.114-122.
7. M. Liu and N. H. Quach, 2001, "Estimation and compensation of gravity and friction forces for robot arms", Journal of Intelligent and Robotic Systems, Vol. 31, pp. 339-354.
8. D. Dang, C. Kang and Y. Kim, 2014, "A study on motion recognition and regeneration method", Journal of the Korean Society for Power System Engineering, Vol. 18, No. 4, pp. 97-103.
9. D. Dang, C. Kang and Y. Kim, 2015, "Robust control system design for robot motion regeneration under disturbance input", Journal of Drive and Control, Vol. 12, No. 3, pp. 1-10.

10. M. Soylemez, M. Gokasan and S. Bogosyan, 2003, "Position control of a single-link robot-arm using a multi-loop PI controller", Proceedings of IEEE Conference, Vol. 2, pp. 1001-1006.
11. H. Delavari, R. Ghedari, A. Ranjbar, S. HosseinNia and S. Momani, 2010, "Adaptive fractional PID controller for robot manipulator", The 4th IFAC Workshop Fractional Differentiation and its Applications, pp. 1-7.
12. F. C. Liu, L. H. Liang and J. J. Gao, 2014, "Fuzzy PID control of space manipulator for both ground alignment and space applications", International Journal of Automation and Computing, Vol. 11, No.4, pp. 353-360.
13. C. Chiena and A. Tayebib, 2008, "Further results on adaptive it erative learning control of robot manipulators", Automatica, Vol. 44, pp. 830-837.
14. P. Tomei, 1991, "Adaptive PD controller for robot manipulators", IEEE Transactions on Robotics and Automation, Vol.7, pp. 565-570.
15. J. Swevers, W. Verdonck and J. De Schutter, 2007 "Dynamic model identification for industrial robots", IEEE Transactions on Control System, Vol. 27, Issue 5, pp. 58-71.
16. N. Bompos, P. Artemiadis, A. Oikonomopoulos and K. Kyriakopoulos, 2007, "Modeling, full identification and control of the Mitsubishi PA-10 robot arm", International Conference on Advanced Intelligent Mechatronics, pp. 1-6.