ROBUST DOUBLE ACTIVE CONTROL SYSTEM DESIGN FOR DISTURBANCE REJECTION

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ABSTRACT

This paper introduces a new disturbance decoupling and rejection method based on robust control framework for a robot system with multiple arms. While in action, the movement of one individual arm of the robot system affects the motion of the other joint, which brings the control performance down. In order to compensate and keep the desirable control performance, the authors designed a double active control system which can effectively reject the direct mutual disturbances. The designed control system consists of two controllers, the first one is an inner loop controller and works as a disturbance observer that attenuates the disturbances. The second one, on the other hand, is an outer loop controller, which was designed based on H_∞ control theory to maintain the system stability and a robust control performance under the uncertainty. The combined control system is applied, simulation and experimental results show that the proposed control system effectively suppress the mutual disturbances, and an enhanced tracking performance is obtained.

Keywords: robust H_∞ control, feedback control, PID control, 2DOF robotic arm.

1 INTRODUCTION

In the midst of the transition to the fourth industrial revolution, the use of automated machines and robots in the industry is of a great importance. Robotic arms, in particular, imitating the human arm movement, they can execute simple, repetitive or difficult tasks on several degrees of freedom (DOF). Thanks to their efficiency and accuracy, they are widely applied in many aspects of the industry, and the marine industry is no exception.

Therefore, in order to control industrial robots to generate accurate motion, multiple control methods were designed. A robust control approach [1], sliding mode control [2], and adaptive control [3] approaches have been developed. However, the mutual disturbances of the joints were not studied thoroughly and had not been directly controlled. Thereupon, an approach to suppress these types of perturbations was developed based on the generation of feedforward control signal computed in advance [4]. This method has two major drawbacks, first, the perturbation suppression is done off-line. Second, there was no room for tackling the unpredicted disturbances that may occur in real time action. Likewise, another approach can be listed, a perturbation observer that has been designed to control the disturbances [5], the observer system, however, is based on estimations and assumed disturbances, which does not often give the desired response.

In the light of all the above, and for the purpose of this paper, the disturbance rejection of the robot arms on each other is achieved by two types of feedback compensators that have been designed, notably a double active control system. First, a real time inner loop controller, designed based on the system configuration, and its objective is to cancel mutual disturbances of the robot arms. However, the input of this controller can be considered as disturbance for the plant which requires the second control system to be designed. Therefore, the outer loop controller was designed based on the robust control theory for better control performances.

In order to verify the efficacy of the proposed control system, a robot system of two-arms, illustrated in Fig. 1, is being considered, and a series of numerical simulations with commercial software MATLAB and Simulink have been investigated. Furthermore, using

WIT Transactions on Engineering Sciences, Vol 125, © 2019 WIT Press
www.witpress.com, ISSN 1743-3533 (on-line)
doi:10.2495/CMEM190081

the graphical programming software LabVIEW, experimental studies have been carried out. Comparative experiments using a PID controller and the proposed control system were performed and analysed, and the results show that the robust double active controller was effective in suppressing disturbances, as well as it gave enhanced and better tracking performances.

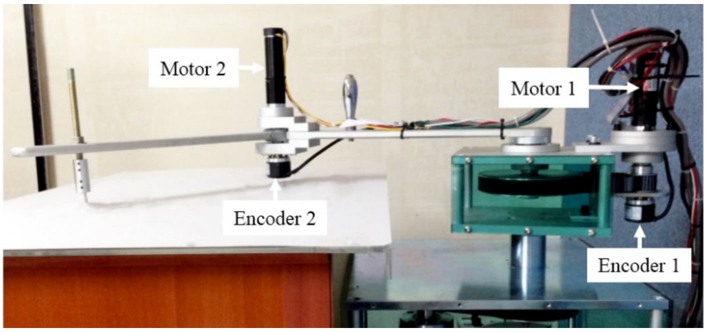


Figure 1: A two-arm robot system.

2 SYSTEM MODELLING AND CONTROLLER DESIGN

2.1 System identification process

In order to design the control system, having a mathematical model that describes the dynamics of the system is compulsory. The Lagrange equations and the identification process using a software are the main methods to obtain a mathematical model of a system. However, the presence of different types of frictions, and difficulties to clearly calculate the different parameters, for instance the inertia moment, determining the system dynamics will be difficult to obtain using Lagrange equations. Therefore, the method adopted provides an individual identification of the system dynamics; each arm of the robot system has been active, one at a time. While the first joint is moving, the transfer function of the active joint is obtained based on the angle of rotation. The inactive joint thus moves and based on its angle of rotation, we obtain the mathematical representation of the active joint disturbance on the inactive one, thus noted $G_d(s)$, and vice versa.

2.2 Disturbance rejection system design

Every real system is subjected to different types of disturbances, whether they occur within the components of the system, or they are some extern disruptions. In fact, let us consider the system with disturbance input depicted in Fig. 2.

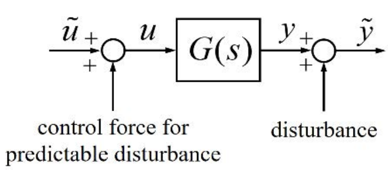


Figure 2: Bloc diagram of a controlled system with input and output signals.

The overall output denoted $\tilde{y}$ is the summation of the output signal y of the plant, and y_d the direct disturbance input signal, which in a muti-joint robot system mainly represents the mutual perurbation.

$$\begin{aligned}\tilde{y}(s) &= y(s) + y_d(s) \\ &= G(s)\cdot u(s) + y_d(s),\end{aligned} \tag{1}$$

where $G(s)$ is the mathematical model of the plant. The objective is to reject the direct disturbances input signal $y_d(s)$. Therefore, if the control input $u(s)$ is to be designed as in the eqn (2), the $y_d(s)$ signal will be eliminated, under the condition that $G(s)$ is proper.

$$u(s) = -G(s)^{-1}\cdot y_d(s)\,. \tag{2}$$

The disturbance input can be expressed as in eqn (3):

$$\begin{aligned}u(s) &= -G(s)^{-1}\cdot G_d(s)\cdot y(s) \\ &= -\bar{G}(s)\cdot y(s),\end{aligned} \tag{3}$$

with, $\bar{G}(s)=G(s)^{-1}\cdot G_d(s)$ as the mathematical representation of the inner loop controller. This input signal may be computed in advance and inserted in the specified time, which will help cancel the mutual disturbances [4]. However, the presence of the inner loop compensator, and the mutual disturbances are drawbacks to the system. Therefore, a robust and optimal H_∞ controller is to be designed to provide better performances. Instead of the classic representation of this controller, is illustrated in Fig. 3(a), where $\Delta(s)$ represents the uncertainties, $G(s)$ is the generalized plant, and $K(s)$ is the controller to be designed.

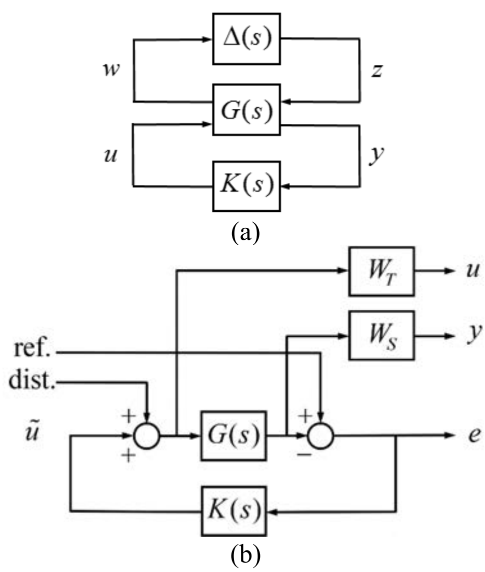


Figure 3: Control system configuration based on robust control framework. (a) Configuration of standard H_∞ control problem; and (b) Mixed sensitivity H_∞ control optimization.

The new configuration of H_∞ control, has a double objective [6]. First, enhancing the tracking performances requires the design of a stabilizing feedback controller *K(s)*, the outer loop controller. Second, the design of an inner loop controller is necessary in order to achieve a robust stability. The weighting functions W_T and W_S are to help minimize the control input u, the plant output y, as well as the error signal e.

For instance, let us consider the two arms robot system illustrated in Fig. 4 with the control system. Simulations and real experiments were conducted based on the identified system and the control system designed.

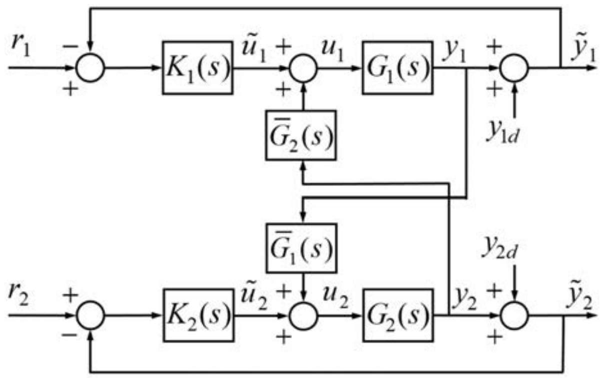


Figure 4: Block diagram of two-arm robot control system.

3 SIMULATION RESULTS

In this section, a comparative study was conducted in order to evaluate the robustness and the control performances of the system. The simulation results were obtained using the designed control system on one hand, and on the other hand experiments using the PID controller were executed.

3.1 Simulation results while the second arm is active

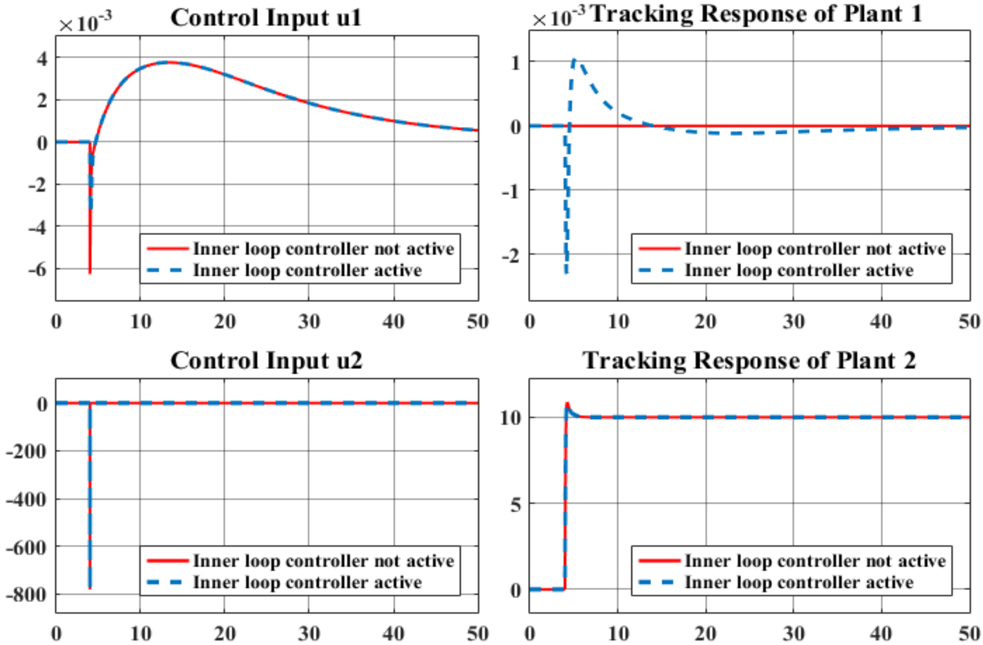
In this experiment, the control input signal to the plant, as well as the overall output of the system are being analysed.

In order to maintain a better tracking performance while the inner loop controller is not active, the control input u_2 in Fig. 5(a) has to be very big to obtain better results. On the other hand, the same control u_1 input is needed, but better tracking performances of the inactive arm, when $\bar{G}_i$ is active.

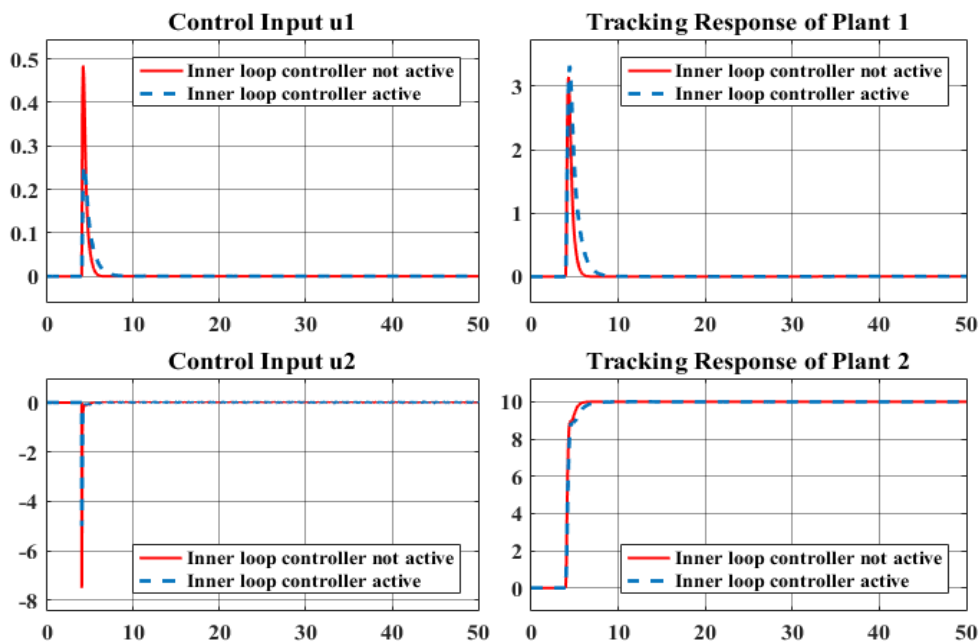
Using the H_∞ controller and activating the inner loop controller, Fig. 5(b), brings the control input signal to half the amount while it was not activated.

3.2 Simulation results while the first arm is active

Similar to the previous case, while the inner loop controller is not active even greater control input signal u_1 is required when the first arm is active, Fig. 6(a). However, the tracking performance improved once the inner loop controller is active, even though the same amount of energy is required for the control input.

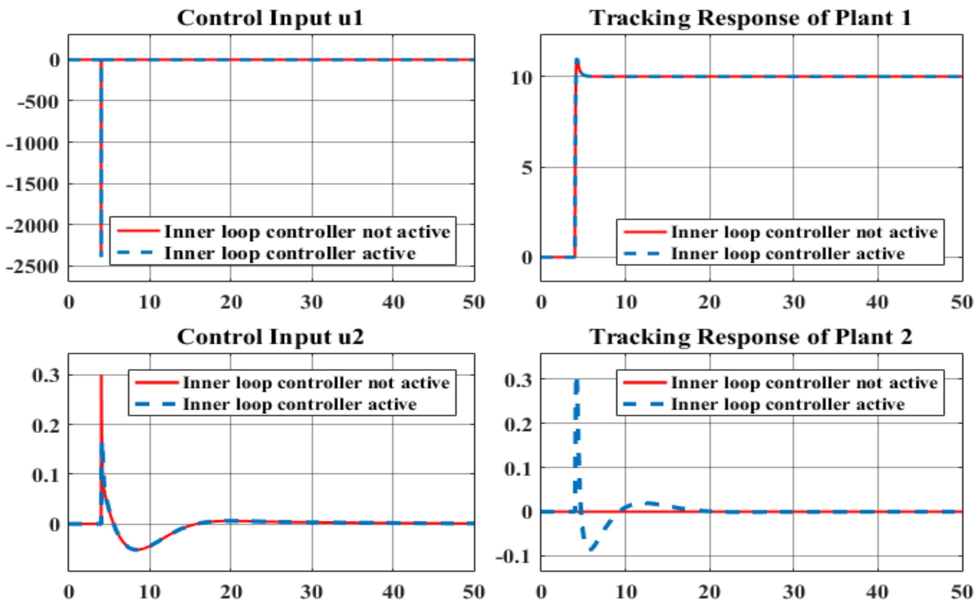


(a)

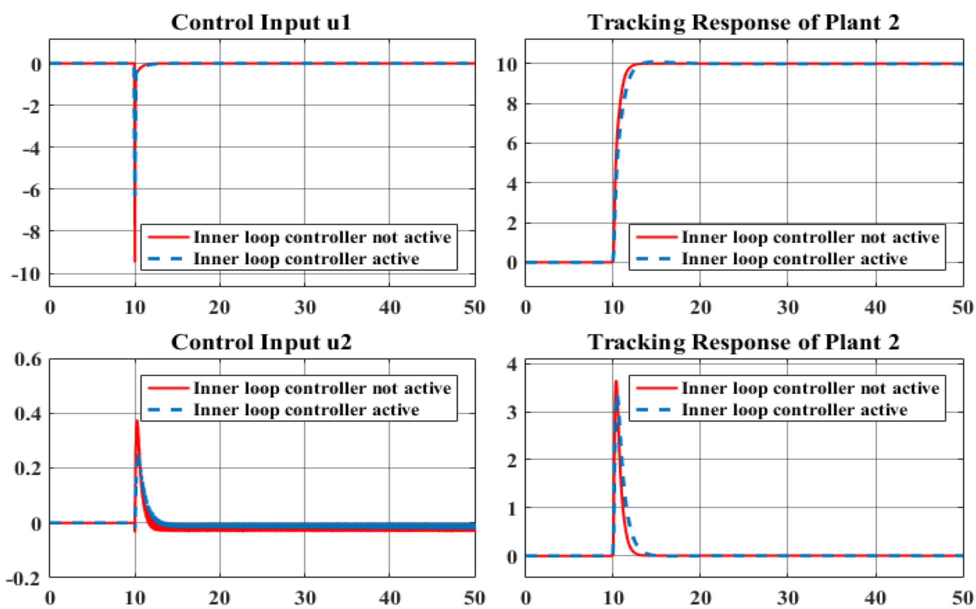


(b)

Figure 5: Step responses while the second arm is active (the first arm is inactive). (a) Response of the PID control system; and (b) Response of the H_∞ control system.



(a)



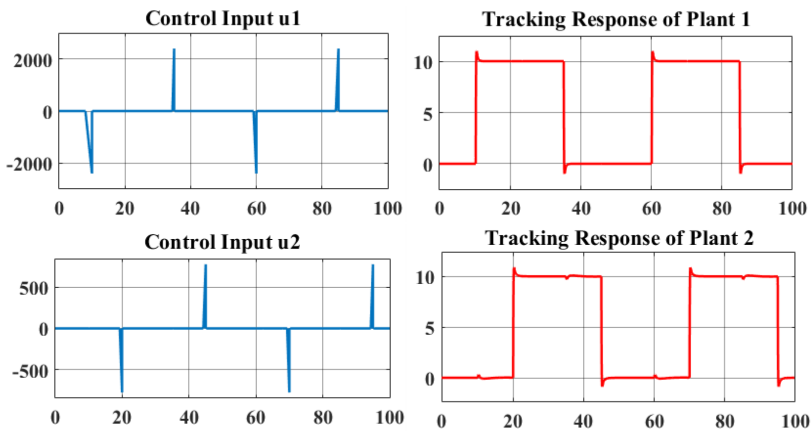
(b)

Figure 6: Step responses while the first arm is active (the second arm is inactive). (a) Response of PID control system; and (b) Response of H_∞ control system.

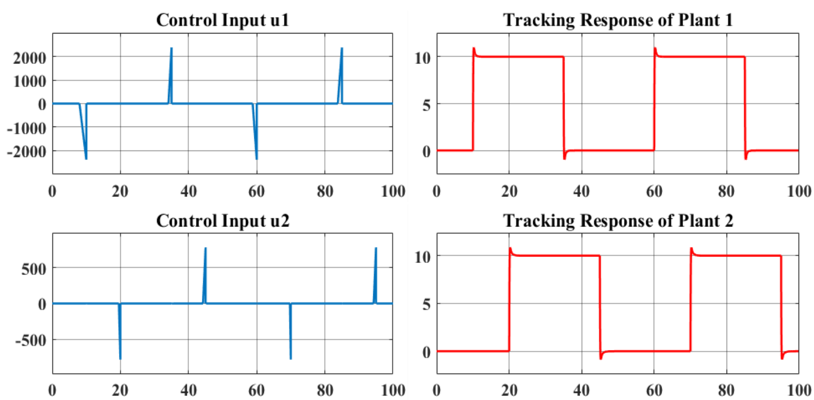
Likewise, using the designed controller and activating the inner loop controller Fig. 6(b) brings the control input signal to half the amount while it was deactivated. Moreover, better tracking performances are provided with much less control input signals.

3.3 Simulation results using the pulse signal

The experiment executed using the PID controller shows good tracking performances, however, a high control input signal is required, which does not change despite the inner loop controller being active, Fig. 7.



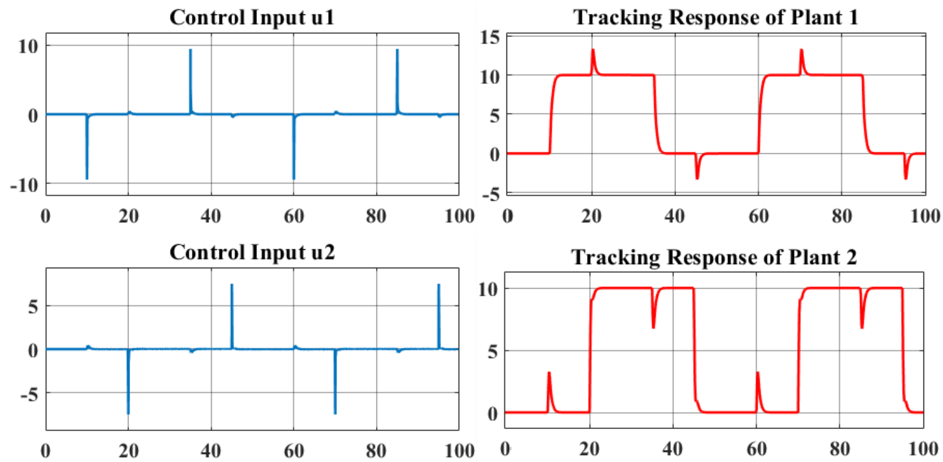
(a)



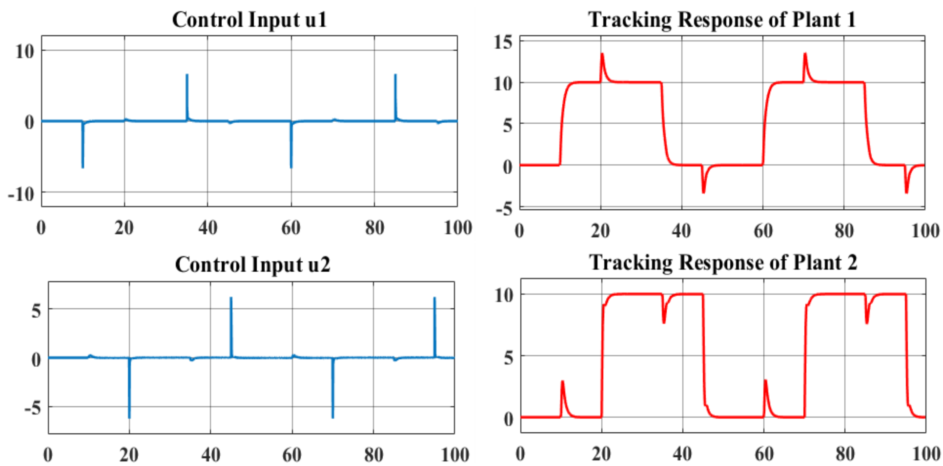
(b)

Figure 7: Pulse type system responses with PID controller. (a) $\overline{G}_i = 0$; and (b) $\overline{G}_i \neq 0$.

The pulse response using the designed control system shows better results than the PID controller, especially, regarding the control input signal, which is the main objective of the H_∞ based control system, Fig. 8(a). Moreover, when the inner loop controller is active, not only the overall output of the plant is better, but also less control input signal is required to maintain the desired response to the refrence, Fig. 8(b).



(a)



(b)

Figure 8: Pulse type system responses with H_∞ controller. (a) $\bar{G}_i = 0$; (b) $\bar{G}_i \neq 0$.

Finally, from the previous simulation results, the designed control system appears to provide better performances, an internal stability, as well as an improved system robustness. Therefore, in the next section, this designed control system will be put to the test with the real system illustrated in Fig. 1.

4 EXPERIMENT RESULTS

In a similar fashion to the simulation tests, a comparison study of the PID and the designed control system responses will be presented. The two arms robot system has been subjected to a pulse reference, and the rotation angles were measured by two incremental encoders.

The experiment results support perfectly the simulation results, and sustain the fact that the proposed control system performs well. The following figures illustrate the results obtained using the PID controller, Fig. 9(a), and using the designed control system, Fig. 9(b).

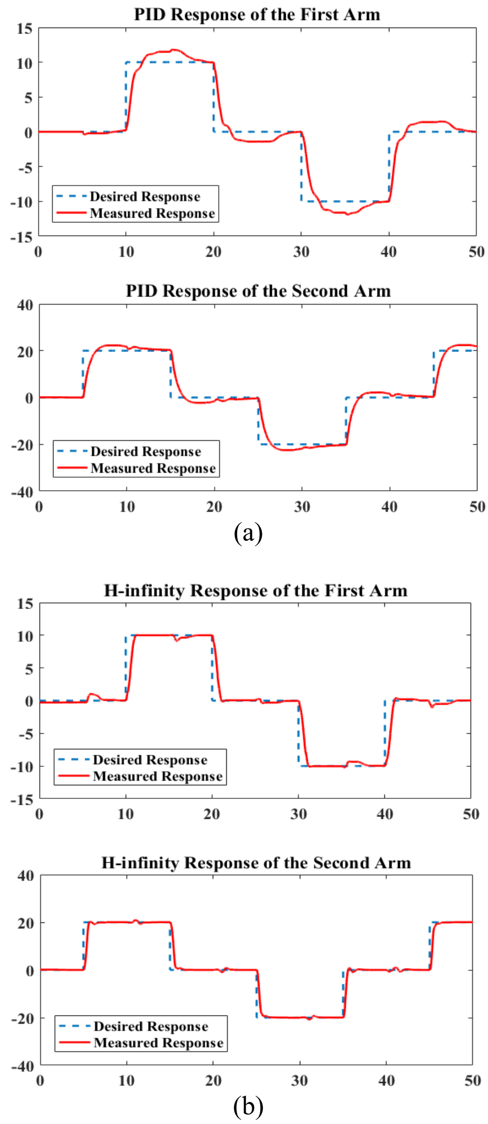


Figure 9: Experimental responses. (a) Responses of PID control system; and (b) Responses of H_∞ control system.

5 CONCLUSION

Throughout this study, the authors proposed a new control method to assure better performances, mutual disturbances rejection, and a robust system stability. The designed control system constitutes of two controllers, an inner loop controller, which improves the internal stability, and an outer loop control system that was designed based on the H_∞ control theory, in order to maintain a better tracking response to the reference signal. The simulation and the experimental results prove the efficacy of the proposed controller, and provides, to a higher standard, a better control for the studied system.

ACKNOWLEDGEMENTS

This research was a part of the project titled “Development of technology to commercialize flatfish automatic grader”, funded by the Ministry of Oceans and Fisheries, Korea. This research was also part of the project titled “Development of the ICT convergence smart sliding docking system”, funded by the Ministry of SMEs and Start-Ups, Korea.

REFERENCES

[1] Dang, D.C. & Kim, Y.B., Accurate motion regeneration technique with robust control approach. *Science and Technology Development*, **18**(K6), pp. 183–191, 2015.

[2] Mohammed, A.A. & Eltayeb, A., Dynamics and trajectory tracking control of a two-link robot manipulator using PID and sliding mode control. *Proceedings of the 2018 International Conference on Computer*, *Control*, *Electrical*, *and Electronics Engineering (ICCCEEE)*, Sudan, 2018.

[3] Tomei, P., Adaptive PD controller for robot manipulators. *IEEE Transactions on Robotics and Automation*, **7**, pp. 565–570, 1991.

[4] Yasuda, M., Osaka, T. & Ikeda, M., Feedforward control of a vibration isolation system for disturbance rejection. *Proceedings of the 35th Conference on Decision and Control*, Kobe, Japan, pp. 1229–1233, 1996.

[5] Song, Y.E., Kim, C.Y. & Lee, M.C., Sliding-mode control with sliding perturbation observer for surgical robots. *IEEE International Symposium on Industrial Electronics*, Seoul, South Korea, 2009.

[6] Gu, D.W., Petkov, P.H. & Konstantinov, M.M., *H-infinity Design: Robust Control Design with MATLAB®*, 2nd ed., Springer, pp. 31–48, 2013.