

Designing a Robust Controller for a 6 Linkage Robot

G. Khamooshian

Abstract—One of the main points of application of the mechanisms of the series and parallel is the subject of managing them. The control of this mechanism and similar mechanisms is one that has always been the intention of the scholars. On the other hand, modeling the behavior of the system is difficult due to the large number of its parameters, and it leads to complex equations that are difficult to solve and eventually difficult to control. In this paper, a six-linkage robot has been presented that could be used in different areas such as medical robots. Using these robots needs a robust control. In this paper, the system equations are first found, and then the system conversion function is written. A new controller has been designed for this robot which could be used in other parallel robots and could be very useful. Parallel robots are so important in robotics because of their stability, so methods for control of them are important and the robust controller, especially in parallel robots, makes a sense.

Keywords—3-RRS, 6 linkage, parallel robot, control.

I. INTRODUCTION

THE design of a robust control system is in the way that the system's dynamic equations must first be extracted. Then, we find the matrices of the state and determine the function of the system conversion with their help. To calculate the weight functions that determine the impact of different factors on the system under consideration, the block diagram of the system is drawn up and the governing relationships are determined. Then, in order to cover the uncertainty effect of the system parameters, the family is defined indefinitely where the block of the system diagram is completed and the input-output ratio (delta functions) is placed smaller than one. Then, it is designed with the help of the Tolbax MiTools in MATLAB and the optimum weight functions, a suitable controller with robust performance. This is an explanation's overview of the whole process of designing a controller for a system.

According to what is said before, we have tried to extract non-complicated equations that could be designed for a control system by considering simplistic assumptions. Uncertainty is then used to model a part of the system's behavior that is not precisely described in the equations. After that, with a robust control design, a system that has a robust stability and performance is found.

In order to perform a robust control system, we need to obtain the dynamic equations of the system to find state-space matrices with the help of these equations and to implement the controllable equations. In 2007, Staicu [1] used the concept of virtual forces to dynamically analyze the 3-RRR mechanism. In 2007, chandeliers and pods [2] offered a kinematic analysis

for symmetric three-degree systems of freedom. Kucuk used the DH Method to analyze the 3-RRR mechanism [3]. Kaveh Kamali and Akbarzadeh presented a new method for direct kinetic analysis of this mechanism in 2008 [4]. But their methodology was long as before. One of the easiest ways to dynamically analyze this mechanism was Yu and his colleagues in 2011 [5]. Noushadi and Milagh in 2012, using the self-learning algorithm, controlled the RRR mechanism but failed to consider the effects of other disturbances. [6] At the same time, Zhang realized that there was a weakness in previous analyzes [7]. This weakness was due to the fact that they did not consider the flexibility of the robot. He performed his analysis using the energy method. In 2014, they used the concept of dynamic difficulty for their analysis [8]. But in 2014, considering the system layout of the mechanism, the dynamics of the system was found, then it was obtained with the help of dynamic hardness, and in 2015, the hardness of each jumble was calculated using static parameters [9]. Abbasi Mashaye et al., in 2015, presented a static analysis of the two robots RC-3 and RRS-3 [10]. In the context of the study of rotational journals in the slang lame mechanism of Rahmanian and Judah in 2015, they published an article [11]. Sinagh and Santacumar made a new assumption for parallel mechanisms. They considered these systems nonlinear disturbances and simulated them and obtained their equations, then reversed control and kinematics of a system of three degrees of freedom. (2-PRP and 1-PPR) [12]. Sinag then controlled another U-shaped PPR-3 mechanism and found its reverse kinematics [13].

A. Assumptions

In this design, direct modeling of the mass of the arms and joints is neglected, and this parameter is indeterminate in the inertia of the whole system. Depending on the different conditions, the friction values can vary, which is modeled in the form of structural uncertainty in the system.

B. System State Equations

The dynamical equations of this system are as follows:

$$\begin{bmatrix} m_p & 0 & 0 \\ 0 & m_p & 0 \\ 0 & 0 & I_p \end{bmatrix} \begin{Bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{\theta} \end{Bmatrix} = \begin{Bmatrix} \sum F_x \\ \sum F_y \\ \sum M \end{Bmatrix} = U \quad (1)$$

$$Z: \text{State Function } Z = \{x \ y \ \theta \ \dot{x} \ \dot{y} \ \dot{\theta}\}^T \quad (2)$$

$$\dot{Z}_{6*1} = A_{6*6}Z_{6*1} + B_{6*3}U_{3*1} \quad (3)$$

$$E: \text{Output } E = \{x \ y \ \theta\}^T \quad (4)$$

$$E_{3*1} = C_{3*6}Z_{6*1} + D_{3*3}U_{3*1} \quad (5)$$

G. Khamooshian is with non-profit higher education Kermanshah University, Iran (phone: +989390437096; e-mail: giti.khamooshian@yahoo.com).

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{bmatrix} D = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad (6)$$

$$B = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} A = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ -K & 0 & 0 & -C & 0 & 0 \\ 0 & -K & 0 & 0 & -C & 0 \\ 0 & 0 & -K & 0 & 0 & -C \end{bmatrix} \quad (7)$$

in which C is damping coefficient and K is stiffness coefficient.

In this system, we have uncertainty for the inertial matrix and the dumping. So, we need to define an indefinite family for them.

Reversed Inertia and Damping

$$\tilde{I} = \frac{1}{I + \Delta\omega_1 I} = \frac{1/I}{1 + \Delta\omega_1} \quad (8)$$

$$\tilde{C} = \frac{C}{1 + \Delta\omega_2 C} \quad (9)$$

We need to find x_1 / x_2 and x_1' / x_2' ratios to obtain a stable stability.

$$\frac{x_1}{x_2} = -\omega_1 \frac{1}{1 + \frac{(c+k/s)I^{-1}}{s}} \Rightarrow \left| \frac{-\omega_1 s^2}{s^2 + csI^{-1} + kI^{-1}} \right| < 1 \quad (10)$$

$$\frac{x_1'}{x_2'} = -\omega_2 \frac{c}{1 + c \frac{(\frac{1}{s})I^{-1}}{1 + (\frac{1}{s})(\frac{k}{s})I^{-1}}} \Rightarrow \left| \frac{-\omega_2 s^2 c - \omega_2 ckI^{-1}}{s^2 + csI^{-1} + kI^{-1}} \right| < 1 \quad (11)$$

We must now guess the weight functions according to the conditions obtained, in order to finally reach the weight functions for which the maximum size μ is smaller than one and the controller is proportional to them.

Several weight functions are guessed for stability (conjecture is obtained with the help of conditions obtained from the previous step), with a maximum value of μ for them smaller than one.

$$w = 0.6 * \frac{(0.5s+0.1)}{0.9s+10} \quad (12)$$

$$w_p = \frac{(0.9s+0.6)}{s+1} \quad (13)$$

II. RESULTS

An instance of the controller of the order 8 is as follows, and this controller maintains the stability of the system.

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K =
194.9061 (s+11.11) (s^2 + 0.521s + 0.2556) (s^2 + 0.4491s + 0.3369) (s^2 + 3.271s + 261.3)
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(s+9.695) (s+1) (s^2 + 0.5214s + 0.2558) (s^2 + 1.543s + 231.7) (s^2 + 32.61s + 779.1)
Continuous-time zero/pole/gain model.
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Fig. 1 Controller obtained from MATLAB software

For each of the four transformation functions, in Figs. 3 and 4, the results obtained with the help of the controller are as follows.

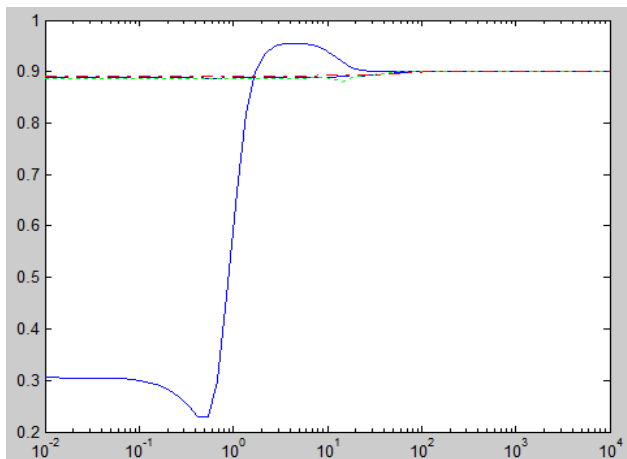


Fig. 2 Maximum MOV value in terms of frequency

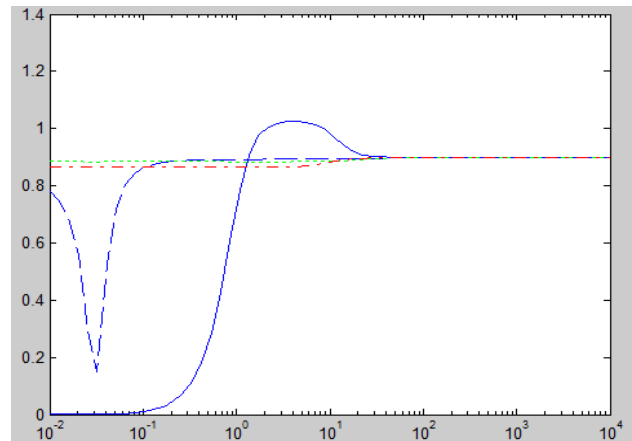


Fig. 3 The maximum value of the MeV quantity in terms of the frequency for the transformation functions given

III. CONCLUSION

As can be seen, the maximum value of μ in all the graphs of the second column is smaller than one, so these functions establish the stability of the system, so the system is controlled. The following diagrams represent the process of improving system performance with the help of the controller. As shown in Fig. 5, the controller eliminates vibration and

system fluctuations, and also significantly reduces the system time (less than one-third of the previous state), and speeds up the system, which is a great point.

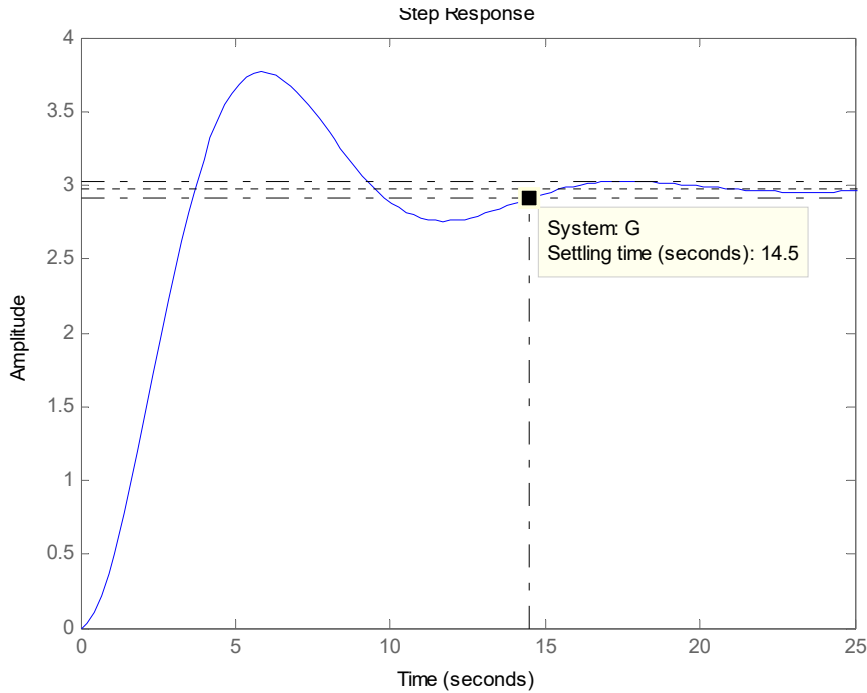


Fig. 4 The system's initial response to the single step input

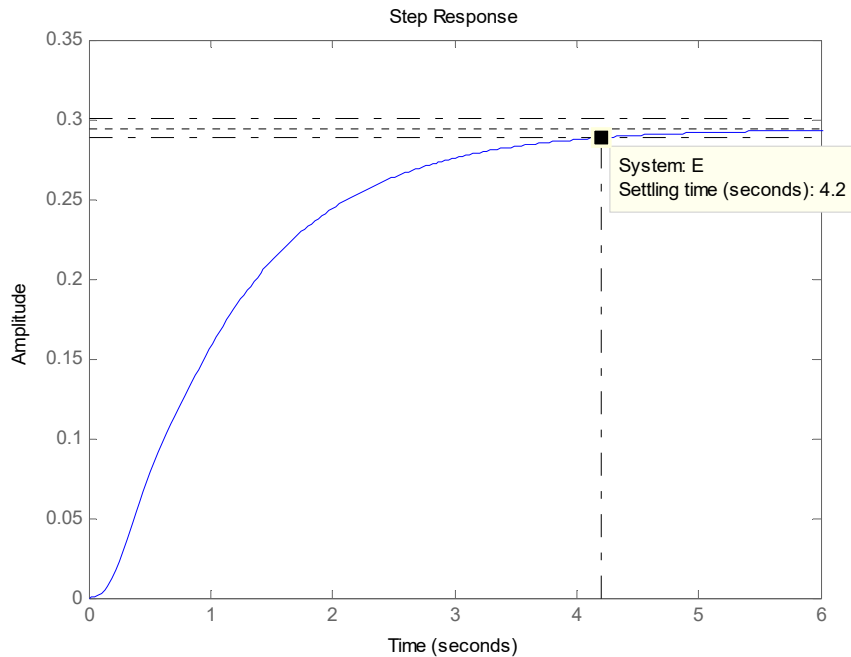


Fig. 5 System response to single step input with controller support

REFERENCES

- [1] Staicu, Stefan. Dynamics of a 3-RRR Spherical Parallel Mechanism Based on Principle of Virtual Powers. A A, 10, 10.
- [2] Chablat, Damien, & Wenger, Philippe. (2007). The kinematic analysis of a symmetrical three-degree-of-freedom planar parallel manipulator. arXiv preprint arXiv:0705.0959.
- [3] Küçük, Serdar. (2012). Inverse Dynamics of RRR Fully Planar Parallel Manipulator Using DH Method: INTECH Open Access Publisher.
- [4] Kamali, Kaveh, & Akbarzadeh, A. (2011). A novel method for direct kinematics solution of fully parallel manipulators using basic regions theory. *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering*, 225(5), 683-701.
- [5] Yu, Yue-Qing, Du, Zhao-Cai, Yang, Jian-Xin, & Li, Yuan. (2011). An experimental study on the dynamics of a 3-RRR flexible parallel robot. *Robotics, IEEE Transactions on*, 27(5), 992-997.
- [6] Noshadi, A, & Mailah, M. (2012). Active disturbance rejection control of a parallel manipulator with self learning algorithm for a pulsating

- trajectory tracking task. *Scientia Iranica*, 19(1), 132-141.
- [7] Zhang, Qinghua, Zhang, Xianmin, & Liang, Jinglun. (2012). *Dynamic analysis of planar 3-RRR flexible parallel robot*. Paper presented at the Robotics and Biomimetics (ROBIO), 2012 IEEE International Conference on.
- [8] Zhang, Qinghua, Fan, Xuerui, & Zhang, Xianmin. (2014). Dynamic Analysis of Planar 3-RRR Flexible Parallel Robots with Dynamic Stiffening. *Shock and Vibration*, 2014.
- [9] Zhang, Xuchong, Zhang, Xianmin, & Chen, Zhong. (2014). Dynamic analysis of a 3-RRR parallel mechanism with multiple clearance joints. *Mechanism and Machine Theory*, 78, 105-115.
- [10] Moshaii, Alireza Abbasi, Masouleh, Mehdi Tale, Zarezadeh, Esmail, & Farajzadeh, Kamran. Two Spherical Three Degrees of Freedom Parallel Robots 3-RCC and 3-RRS Static Analysis, World Academy of Science, Engineering and Technology Online Publication, Vol. 9, No. 6, 2015.
- [11] Rahmanian, Sasan, & Ghazavi, Mohammad Reza. (2015). Bifurcation in planar slider–crank mechanism with revolute clearance joint. *Mechanism and Machine Theory*, 91, 86-101.
- [12] Singh, Yogesh, & Santhakumar, M. (2015). Inverse dynamics and robust sliding mode control of a planar parallel (2-PRP and 1-PPR) robot augmented with a nonlinear disturbance observer. *Mechanism and Machine Theory*, 92, 29-50.
- [13] Singh, Yogesh, Vinoth, V, Kiran, Y Ravi, Mohanta, Jayant Kumar, & Mohan, Santhakumar. (2015). Inverse dynamics and control of a 3-DOF planar parallel (U-shaped 3-PPR) manipulator. *Robotics and Computer-Integrated Manufacturing*, 34, 164-179.