

Control of a Robot Manipulator using Model Following Control



Rajesh Layek, S. Mukherjee

Abstract: In this work the simulation results of a 2 degree of freedom plant driven by model are shown. Here Model following control (MFC) system is applied to operate the plant in a better way. Initially a model is constructed, whose states are ideal with respect to the control parameters. The plant and the model essentially have same physical parameters. An input is given to the model and the plant is run by the errors, computed by comparing the states of the plant and model. In this way the plant is forced to follow the ideal states of the model. The results show that the plant is able to follow the model very accurately. The robust control observed in the scheme can be easily implemented for better performance of industrial robots.

Keywords: Gain, Model following control, Robot manipulator, Speed of response.

I. INTRODUCTION

Various advanced types of controllers are used for precision control of robot. Model following control (MFC) is one of them. The model can either be a mathematical model or a physical model or an analog model made of electronic circuits [1], [2]. The actual system is then forced to follow the ideal response provided by the model so as to perform its given task in the best possible way [3]. Here a cylindrical robot manipulator is considered whose shoulder joint is driven by a motor through a belt pulley system. It is a simple, flexible, lightweight, low cost power transmission system. However, the nonlinear friction, vibration and belt flexibility present a set of negative factors for precision control which may limit its reliability [4]-[7]. The smaller pulley is connected to the motor which drives the bigger pulley through a belt. The bigger pulley is fixed to the robotic arm whose positioning is to be controlled [8].

II. NOMENCLATURE

J_{m1}, J_{m2} = moment of Inertia of smaller and bigger pulley (model), kg-m²
 r_{m1}, r_{m2} = radius of smaller pulley and bigger pulley (model), m
 θ_{m1}, θ_{m2} = system co-ordinates (model), rad
 $\dot{\theta}_{m1}, \dot{\theta}_{m2}$ = velocity co-ordinates (model), rad
 K_m = belt stiffness (model), N-s/m

C_m = damping coefficient of the belt (model), N-s/m
 C_{m1}, C_{m2} = damping coefficient of the damper attached to smaller pulley and bigger pulley (model), N-m-s/rad
 T_m = input torque (model)
 i_m = armature current (model)
 μ = motor torque constant
 R = step input (model)
 A = Amplifier gain (model)
 e = $(R - \theta_{m2})$ = Feedback error (model)
 J_{p1}, J_{p2} = moment of Inertia of smaller pulley and bigger pulley (plant), kg-m²
 r_{p1}, r_{p2} = radius of smaller pulley and bigger pulley, (plant), m
 θ_{p1}, θ_{p2} = system co-ordinates (plant), rad
 $\dot{\theta}_{p1}, \dot{\theta}_{p2}$ = velocity co-ordinates (plant), rad
 K_p = belt stiffness (plant), N-s/m
 C_p = Damping coefficient of the belt (plant), N-s/m
 C_{p1} = damping constant (plant), N-m-s/rad
 T_p = input torque (plant)
 i_p = armature current (plant)
 A_{p1}, A_{p2} = position error feedback gains (plant)
 A_{d1}, A_{d2} = velocity error feedback gains (plant)
 $e_1 = (\theta_{m1} - \theta_{p1})$ = position error of smaller pulley
 $e_2 = (\theta_{m2} - \theta_{p2})$ = position error of bigger pulley
 $\dot{e}_1 = (\dot{\theta}_{m1} - \dot{\theta}_{p1})$ = velocity error of smaller pulley
 $\dot{e}_2 = (\dot{\theta}_{m2} - \dot{\theta}_{p2})$ = velocity error of bigger pulley

III. THE MODEL FOLLOWING CONTROL SCHEME

The model following control scheme envisages a model whose response is ideal in terms of the control parameters and the states of the plant are made to follow the ideal states of the model. Accordingly an ideal model is constructed, whose states are ideal during its response [9]. A reference input is given to the model and the plant is run by the errors, computed from the states of the model and the plant. The errors are fed to the system after providing suitable error feedback gains. These errors in turn run the plant whose states are constraint to follow the ideal states of the model [8], [10]. The model following control scheme is shown in fig. 1.

Manuscript received on February 10, 2020.
 Revised Manuscript received on February 20, 2020.
 Manuscript published on March 30, 2020.

* Correspondence Author

Rajesh Layek*, PG student, Department of Mechanical Engineering, Jalpaiguri Government Engineering College, Jalpaiguri, India.

Dr. S. Mukherjee, Professor, Department of Mechanical Engineering Jalpaiguri Government Engineering College, Jalpaiguri, India.

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>)

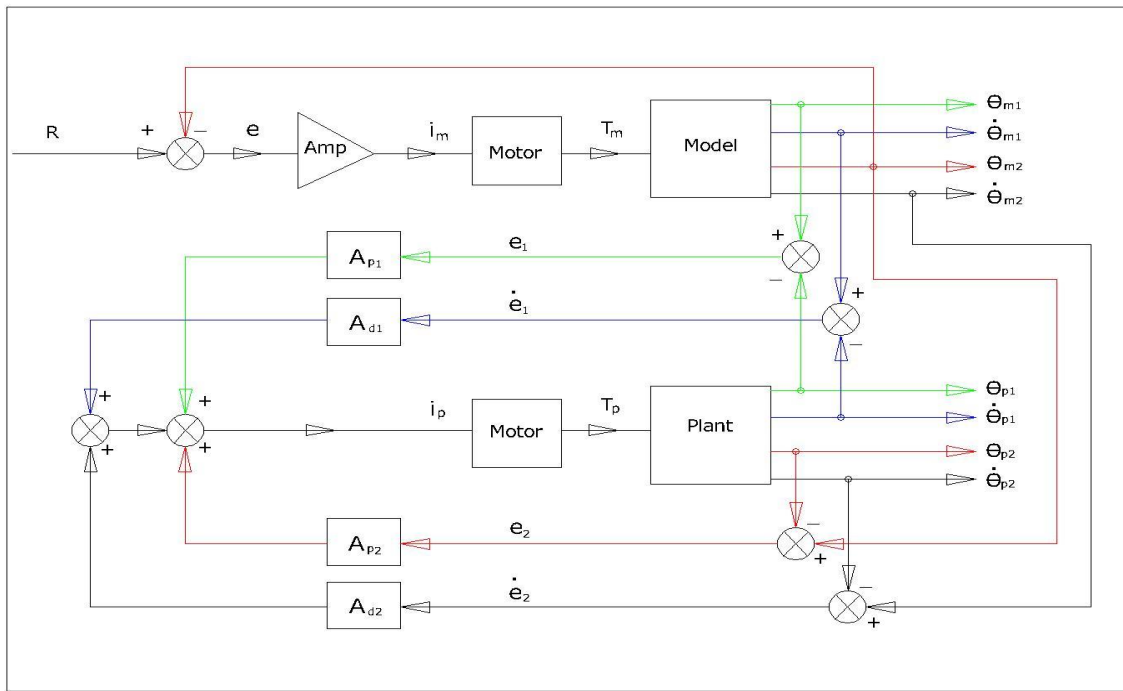


Fig. 1. The model following control scheme

IV. MATHEMATICAL MODEL

The mathematical formulation of the model and plant are given as follows.

(A) The Ideal Model

The model considered here is a theoretical one having the same physical parameters as the actual system [11], [12]. It has two inertias connected by a flexible belt. Larger inertia represents the robot manipulator. It is constructed in such a way that its response is ideal, which is done by adjusting the amplifier gain [4]. Fig. 2 [8] shows the schematic diagram of the ideal model.

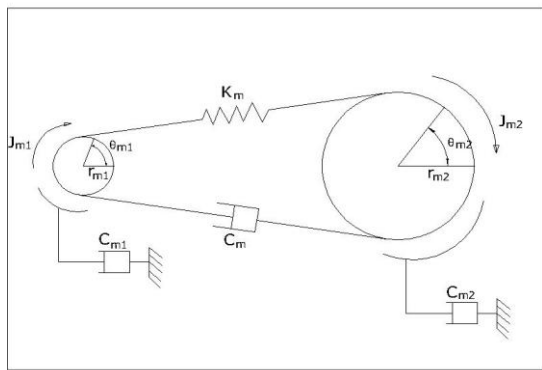


Fig. 2. The ideal model

The equations of the ideal model are given by

$$J_{m1}\ddot{\theta}_{m1} + C_{m1}\dot{\theta}_{m1} + C_m r_{m1} (r_{m1}\dot{\theta}_{m1} - r_{m2}\dot{\theta}_{m2}) + K_m r_{m1} (r_{m1}\theta_{m1} - r_{m2}\theta_{m2}) = T_m = \mu i_m \dots\dots\dots(1)$$

Where, $i_m = A (R - \theta_{m2}) = Ae$

$$J_{m2}\ddot{\theta}_{m2} + C_{m2}\dot{\theta}_{m2} + C_m r_{m2} (r_{m2}\dot{\theta}_{m2} - r_{m1}\dot{\theta}_{m1}) + K_m r_{m2} (r_{m2}\theta_{m2} - r_{m1}\theta_{m1}) = 0 \dots\dots\dots(2)$$

(B) The Actual System (Plant)

Here the actual system is a cylindrical robot manipulator where the bigger pulley represents the shoulder joint of the robot arm. The positioning of the arm is controlled by controlling this joint. The movement of the shoulder joint is controlled by forcing the states of the system to follow the ideal states of the model. The errors are given by:

$$e_1 = (\theta_{m1} - \theta_{p1}), \quad e_2 = (\theta_{m2} - \theta_{p2}), \quad \dot{e}_1 = (\dot{\theta}_{m1} - \dot{\theta}_{p1}), \quad \dot{e}_2 = (\dot{\theta}_{m2} - \dot{\theta}_{p2})$$

These errors are not sufficient to follow the response of the model. So, suitable gains are adopted i.e. $A_{p1}, A_{p2}, A_{d1}, A_{d2}$ with the errors to get better response from the plant [13]. Now four suitable error gains are selected in such a way that the plant response should follow the response of the model. The suitable gains are obtained by varying one gain at a time keeping other three constant at some lower values [14]. The schematic diagram of the plant is represented in fig. 3.

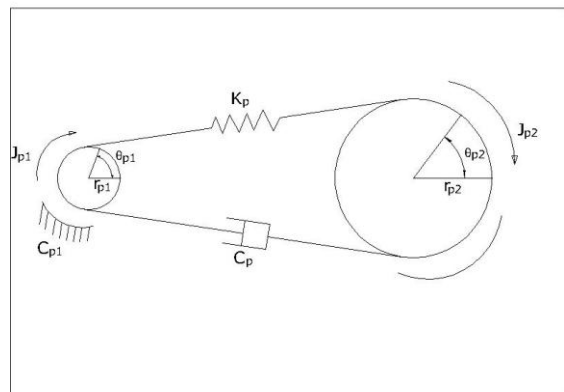


Fig. 3. The actual system

The equations of the actual system are given by

$$J_{p1}\ddot{\theta}_{p1} + C_{p1}\dot{\theta}_{p1} + C_p r_{p1} (r_{p1}\dot{\theta}_{p1} - r_{p2}\dot{\theta}_{p2}) + K_p r_{p1} (r_{p1}\theta_{p1} - r_{p2}\theta_{p2}) = T_p = \mu i_p \dots\dots\dots(3)$$

Where,

$$i_p = A_{p1}(\theta_{m1} - \theta_{p1}) + A_{p2}(\theta_{m2} - \theta_{p2}) + A_{d1}(\dot{\theta}_{m1} - \dot{\theta}_{p1}) + A_{d2}(\dot{\theta}_{m2} - \dot{\theta}_{p2}) = A_{p1}e_1 + A_{p2}e_2 + A_{d1}\dot{e}_1 + A_{d2}\dot{e}_2$$

$$J_{p2}\ddot{\theta}_{p2} + C_{p2}\dot{\theta}_{p2} + C_{p1}\dot{\theta}_{p2} + K_{p1}(\theta_{p2} - \theta_{p1}) + K_{p2}\theta_{p2} - r_{p1}\theta_{p1} = 0 \quad \dots\dots\dots (4)$$

V. EXAMPLE

A practical example is considered here to illustrate the effectiveness of the proposed MFC scheme.

Parameters of the plant and the model are:

- | | |
|------------------------------------|------------------------------------|
| $r_{p1} = 9.55 \text{ mm};$ | $r_{m1} = 9.55 \text{ mm};$ |
| $r_{p2} = 38.2 \text{ mm};$ | $r_{m2} = 38.2 \text{ mm};$ |
| $J_{p1} = 0.0018 \text{ kg m}^2;$ | $J_{m1} = 0.0018 \text{ kg m}^2;$ |
| $J_{p2} = 0.071 \text{ kg m}^2;$ | $J_{m2} = 0.071 \text{ kg m}^2;$ |
| $C_p = 2500 \text{ N s/m};$ | $C_m = 2500 \text{ N s/m};$ |
| $C_{p1} = 0.05 \text{ N ms/rad};$ | $C_{m1} = 0.5 \text{ N ms/rad};$ |
| $K_p = 5 \times 10^5 \text{ N/m};$ | $C_{m2} = 3 \text{ N ms/rad};$ |
| $\mu = 1.25 \text{ N m/A};$ | $K_m = 5 \times 10^5 \text{ N/m};$ |
| $A_{p1}=9; A_{p2}=1;$ | $\mu = 1.25 \text{ N m/A};$ |
| $A_{d1}=1.28; A_{d2}=1.28;$ | $A = 70;$ |
| | $R = 1;$ |

VI. SIMULATION RESULTS

The simulation results of the system are obtained by solving the model and plant equations in a digital computer [15].

Fig. 4 shows the ideal response of the model found by adjusting the amplifier gain A. The response is very fast (about 0.07 sec) and has no overshoot. Therefore the states of the model can be considered ideal at any point of time.

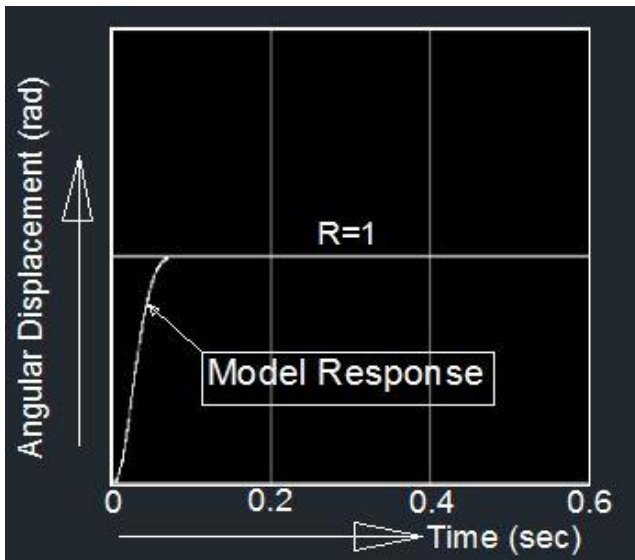


Fig. 4. Model response

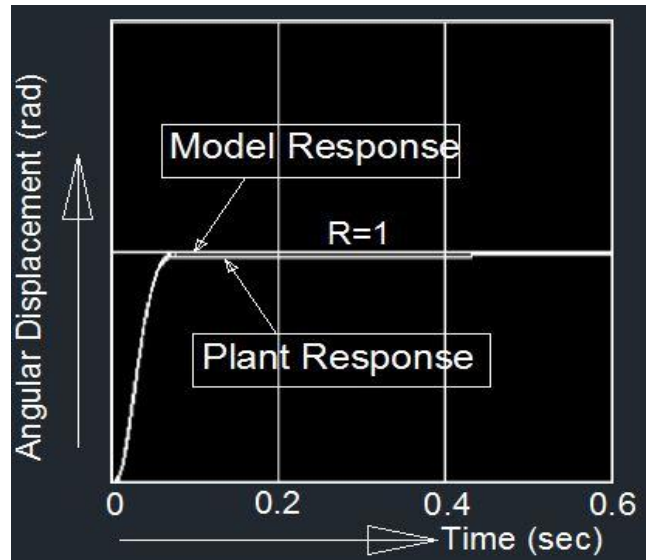


Fig. 5. Model and plant response ($A_{p1}=1, A_{p2}=1, A_{d1}=1, A_{d2}=1$)

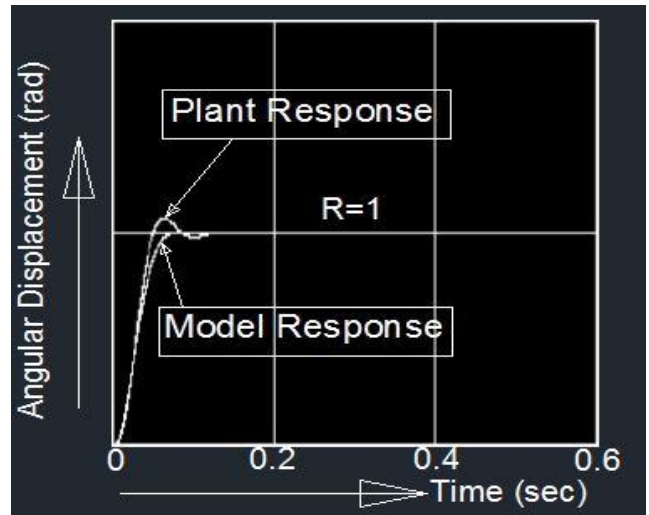


Fig. 6. Model and plant responses ($A_{p1}=100, A_{p2}=1, A_{d1}=1, A_{d2}=1$)

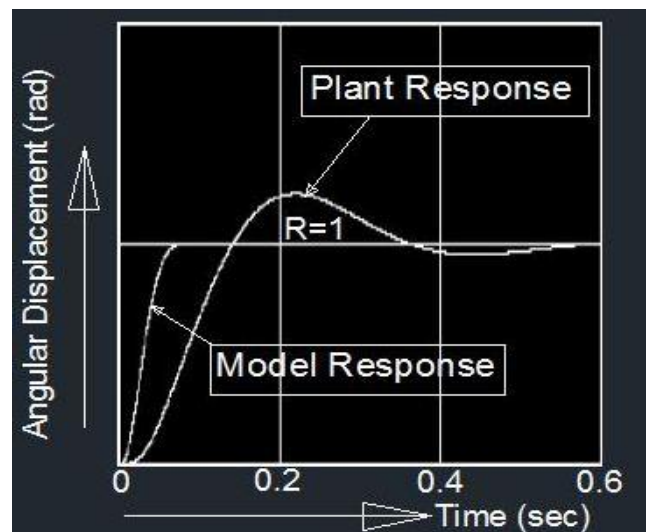


Fig. 7. Model and plant responses ($A_{p1}=1, A_{p2}=1, A_{d1}=0.01, A_{d2}=0.1$)

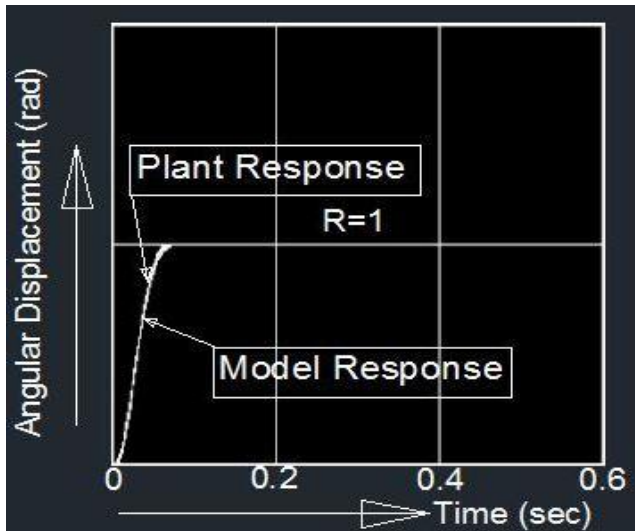


Fig. 8. Model and plant responses ($A_{P1}=9, A_{P2}=1, A_{d1}=1.28, A_{d2}=1.28$)

Responses of the model and plant are found for different error feedback gains having large ranges of variations. All the gains are varied one by one to find the effect of the gains individually on the response of the system. Fig. 5 to fig. 8 show some of the responses for different gain values.

Fig. 5 represents the responses of the model and the plant for gains $A_{P1}=1, A_{P2}=1, A_{d1}=1, A_{d2}=1$. It is seen that the plant response is initially fast but steady error remains for a large period of time and it reaches the desired point after a considerably high time period.

Responses of the model and plant are shown in fig. 6 for gains $A_{P1}=100, A_{P2}=1, A_{d1}=1, A_{d2}=1$. Though there is very little difference between the plant and model responses, the plant response is faster than the model and it has a little overshoot which settles down around 0.12 sec.

Fig. 7 shows the responses of the model and plant for gains $A_{P1}=1, A_{P2}=1, A_{d1}=0.01, A_{d2}=0.1$. The plant response is seen to be much slower, has large overshoot and settling time is quite high (around 0.9 sec).

The best response of the plant following the ideal response of the model is shown in fig. 8. There is practically no difference between the model and plant responses and the plant is perfectly following the ideal states of the model. The gain values for the best response are $A_{P1}=9, A_{P2}=1, A_{d1}=1.28, A_{d2}=1.28$.

VII. CONCLUSION

The MFC scheme depicts that the plant follows the ideal response of the model very accurately and precisely. Here the plant is run only through the errors, generated from the differences of the states of model and plant. It is practically impossible to differentiate the model and plant responses when proper combination gains are provided as shown in fig. 8. The proposed control scheme is simple without any adaptive algorithm and can be easily implemented. The robust control found in this simple and cost effective scheme may be easily adopted for wider use in industrial robots.

REFERENCES

1. Tianjin Wang, Haoyu Zhao, Hongwei Zhao, Xingqian Li, Ziguang Xu, "Intelligent Robot Safety Control System Based on MFC" *International Conference on Robotics and Artificial Intelligence*, December 2017 Pages 101–104.
2. Stanislaw Skoczowski, "Robust model following control with use of a plant model", *International Journal of Systems Science*, 2001, volume 32, number 12, pages 1413-1427.
3. S. Dubowsky, D. T. DesForges, "The Application of Model-Referenced Adaptive Control to Robotic Manipulators", *ASME*, September 1979, Vol.-101, Issue-3: 193-200 (8 pages).
4. Stanislaw Skoczowski, Steran Domek, "Pid Robust Model Following Control", Copyright @ IFAC Digital Control: Past, Present and Future of PIO Control, Terrassa, Spain, 2000.
5. Sudipta Ghosh, S. Mukherjee, "PID Control of a Single Degree of Freedom Flexible Robot Manipulator", *International Journal of Research in Engineering Application & Management (ijream)*, Vol-04, Issue-03, June, 2018
6. Ms. Vaijayanti B, "Robotic Arm Control Using PID Controller And Inverse Kinematics", 2017 *IJEDR*, Volume 5, Issue 2, ISSN: 2321-9939.
7. Andromachi G. Katsioulia, Yannis L. Karnavas, Yiannis S. Boutalis, "An Enhanced Simulation Model for DC Motor Belt Drive Conveyor System Control", 2018 7th *International Conference on Modern Circuits and System Technologies*, DOI: 10.1109/MOCASST.2018.8376636.
8. S. Mukherjee & S. N. Sengupta, "Control of a robotic manipulator-a model following approach", *Indian Journal of Engineering & Material Sciences*, Vol. 1, April, 1994, pp 70-76.
9. Magdi S. Mahmoud & Ahmed A. Bahnasawi, "A design approach to adaptive model-following control of robotic Manipulator", *Journal of Intelligent and Robotic Systems*, 10, pages 191–207 (1994)
10. Raham H. Mohammed, Fahmy Bendary and Kamel Elserafi, "Trajectory Tracking Control for Robot Manipulator using Fractional Order-Fuzzy-PID Controller", *International Journal of Computer Applications*, 134(15):22-29 · January 2016.
11. Kim, B.K. and Shin, K.G., "An adaptive model following control of industrial manipulators", *IEEE Trans. Aerospace Electronic Syst.* AES-19 (1983), 805–814.
12. Vinzenz Bargsten, Pablo Zometa, and Rolf Findeisen, "Modeling, Parameter Identification and Model-Based Control of a Lightweight Robotic Manipulator", 2013 *IEEE International Conference on Control Applications (CCA)*, DOI: 10.1109/CCA.2013.6662756.
13. S. Mukherjee, S. Mukhopadhyay, S. N. Sengupta "Model Following Control of a Variable Inertia Positioner", *The International Journal of Robotics Research*, Vol -12, Issue -5, 1993.
14. Wen Yu and Jacob Rosen, "Neural PID Control of Robot Manipulators with Application to an Upper Limb Exoskeleton", *IEEE*, Volume: 43, Issue: 2, April 2013, Page(s): 673 – 684, DOI: 10.1109/TSMCB.2012.2214381
15. HMC soft book, "A Beginner's Guide to Free Basic", by Richard D. Clark, Ebben Feagan, 2013.

AUTHORS PROFILE



Rajesh Layek, PG student, Department of Mechanical Engineering, Jalpaiguri Government Engineering College, Jalpaiguri, India. His area of interest is Robotics.



Dr. S. Mukherjee, Professor, Department of Mechanical Engineering Jalpaiguri Government Engineering College, Jalpaiguri, India. His area of interests are Robotics, Operations Research, Machine Dynamics. He has done extensive research on the above fields and published a number of papers in international and national journals.