Modeling of two cooperative manipulators to handle an object

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Abstract

Trajectory tracking in cooperative manner of robot manipulators in the industrial applications is most challenging issue. In cooperative robot manipulators needs to consider not only collaborative work on the workspace but also has to overcome with uncertainties and external disturbances. Based on these limitation and estimation parameters in robot manipulators, these kinds of systems have more complex and nonlinear dynamic model. In face with nonlinear systems some soft computing methods like fuzzy logic systems are so sufficient behavior. In addition, PID controllers are so qualified controller in the industrial applications because of their simple structure in the implementation. In this work, for handling a lightweight beam with two cooperative robot manipulators on the road to achieve a destination is proposed a hybrid controller which can reject uncertainties automatically. This controller consists of two elements, fuzzy logic controller and PID controller. Fuzzy logic controller is employed for to approximate parameters of PID controller in the system. In this system angular measurement of joints is considered. To comparison, the proposed controller compares with two other controllers, conventional PID controller with Ziegler-Nichol's method and conventional fuzzy controller on the system with two 3-DOF robot manipulators. Simulation results show the hybrid controller has better performance than two others to handle a hypersensitive beam with two cooperative manipulators.

1.Introduction

In the past few years, the research in cooperative robot manipulators has received considerable attention. Actually, because of some specific properties (such as providing lower cost in product, quality, and higher flexibility than specialized machines) that robot manipulators have, they play an important role in the industry. Cooperative robot manipulators as main part of robotic systems have more complicated nonlinear dynamical system which operates in unstructured environment in the presence of uncertainties and external disturbance. Based on this nonlinear dynamical property in robot manipulators, performance of trajectory tracking is limited. Overcoming with this limitation is most important challenging issue in the control of robot manipulators. PID controllers have been widely used in industry due to the facts that they have simple structures and they assure acceptable performance for the majority of industry processes. Because of their simple structure, PID controllers are easy to design, operate and maintain. In this controller, have various parameters tuning methods for conventional PID controllers have been proposed. In this paper, we used Ziegler Nichol's method for controller parameters. Fuzzy logic control can provide a solution based on the experiences of human operate. These fuzzy control systems often give better results than the original conventional PID type control systems. One of the prominent and efficient ways is applying fuzzy logic to the design of PID controllers. Tarn at el. [1] presented a transformation approach for robot manipulators based on dynamical equations of system which is nonlinear. A nonlinear feedback controller is also proposed in [2]. In [3] is presented a method for robot control which is considered only measurement of joint position. Some researchers have been studied on fuzzy controller for robot manipulators [4-12]. In 2001 Gueaieb at el. [13] was introduces a new MIMO fuzzy algorithm for cooperative robot manipulators without need to model of the system. After this some other studies was introduces for cooperative robot manipulators [13-23]. In [24] a fuzzy controlling approach was presented that requires the knowledge of a nominal values of inertia matrix. In addition in this method an observer is offered not only used joint position measurement but also used joint velocity measurements. In addition [25-34] works have focus some force, position and impedance measurements with fuzzy for robot manipulators. In [35] a decentralized adaptive control scheme is proposed which is based on position and internal force measurements. The controlling scheme contains MIMO fuzzy logic engine and online adaptation mechanism. This adaptive mechanism does not require prior knowledge of dynamical model of multiple cooperative manipulator system. The stability of controlling system guarantees Lyapunov method. Based on simulation results errors of position and internal forces converge to zero under uncertainties and external disturbances. Caccavale at el. [36] is proposed impedance controlling scheme for six-DOF dual arm robot manipulator. In [37] for dynamic friction of each joint of a robot manipulator is proposed an intelligent tracking control design. Tracking control design is based on adaptive fuzzy system. This adaptive fuzzy system approximates nonlinear friction over values of input. [38] A new adaptive neuro-fuzzy control algorithm is proposed for robot manipulators. This controller is designed with uncertainties based on position and velocity measurements. This algorithm includes two elements, adaptive neuro-fuzzy controller and conventional controllers. The controller simulates on the six DOF PUMA robot arm which is shows it has better performance than conventional adaptive controller. An adaptive fuzzy neural network controller for robot manipulators is proposed in [39] [40]. The controller learns inverse dynamics of robot manipulators by feedback controller and multiple fuzzy neural networks. Parameters of fuzzy neural network get from incremental learning algorithm which is reformed online in the presence of uncertainties. For stability is used Lyapunov method. The controller is applied to control a two-link robot manipulator. Several studies were considered adaptive fuzzy sliding mode control for trajectory tracking of robot manipulators [41-51]. In [52] designed, developed and implemented a new controller for tracking control of a two-link SCARA robot. This method is an online adaptive MIMO fuzzy switching controlling method which is used for a nonlinear plant. For fuzzy controller is used Takagi-Sungeno's architecture with online self-tuning. An adaptive fuzzy immune PID controller is presented in [53]. This controller is for multi joint robots and consists of feedback mechanism, fuzzy control theory and PID controller. So, this combination was used for offline controlling system. Hence, for online controlling is used genetic algorithm. The controller was simulated on two- joint robot manipulator which shows high precision and speed in tracking control. Furthermore, some adaptive fuzzy sliding mode observers for robot manipulators with uncertainties are proposed in [53-56]. A tracking controller method for a class of robot manipulators is presented in [57] which is a used only angular position. In this system is considered the system parameters, nonlinear terms, external disturbances, friction affection the each joint of robot manipulator. For friction effects is considered viscous friction, coulomb and stribeck friction. This compensator includes two elements, linear feedback control and high gain estimator. In the feedback controller linearizing control law lumped uncertainties into an unknown state which needs the knowledge of the unknown state. To overcome with this problem is used high gain state estimator. In this paper, cooperative robot manipulators system handling very sensitive materials is proposed. Suggested system is including two robot arms and a lightweight beam. These arms carry the beam along the road path. Every robot has three degree of freedom. Target of these robots is the movement of hyper sensitive beam along the road so that the beam has minimum angular changes. Because of existence hyper sensitive materials within beam, this system tries to move it with two robot manipulators. In this paper in section 2 is presented structure of hybrid controller and other two methods. In section 3 is considered simulation results.

2.Structure of hybrid controller

The proposed system is containing two 3-DOF robot manipulators to handle a hyper sensitive beam along the road. The schematic of the system is shown in figure 1.

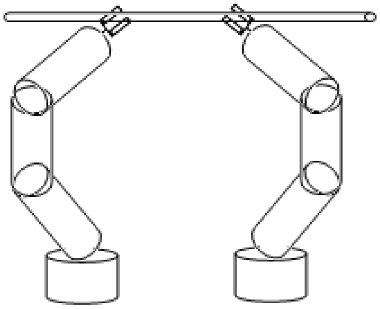


Figure 1: two robots system include two 3DOF arm robot

In this system the angular measurement is considered. The one hypothesis is that the end-effector of each robot manipulators is fixed. Here, the controlling system is based on angle of beam relative to road surface. This causes the beam to achieve the destination with minimum of shakes and strokes. This system is based on angle control relative to road. So, error angle of beam equals to one degree and control accomplishes on the basis of that. Primitive closed loop system is shown in figure 2.

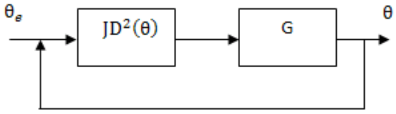


Figure 2: primitive closed loop system for input of beam torque and output of beam angle

$$\tau = JD^2(\theta) \qquad (1)$$

τ is beam torque, J is a unity beam inertia default. θ_ϵ is desired angle value, θ is actual angle value. In figure 2, gain function is:

$$G = \frac{\theta}{JD^2(\theta)} \qquad (2)$$

In the frequency domain, we'll have:

$$G(s) = \frac{1}{s^2} \qquad (3)$$

Because of existing three joint for transmitting error angle of beam to controller, we are considering delay error that is equal to e^{θ_e} and using second order approximation that is:

$$e^{-s} \approx \frac{s^2 - 6s + 12}{s^2 + 6s + 12} \qquad (4)$$

General form of gain function is:

$$G(s) = \frac{s^2 - 6s + 12}{s^2(s^2 + 6s + 12)} \qquad (5)$$

According to the Routh method [62], it's unstable. To solve this problem, a compensator is added parallel to feed forward block as shown in figure 3.

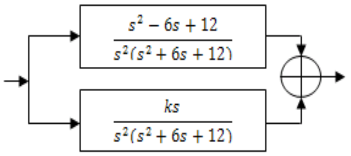


Figure 3: stability compensator

The system transfer function is now:

$$G(s) = \frac{ks}{s^2(s^2 + 6s + 12)} + \frac{s^2 - 6s + 12}{s^2(s^2 + 6s + 12)} = \frac{s^2 + (k-6)s + 12}{s^2(s^2 + 6s + 12)} \qquad (6)$$

$$T(s) = \frac{G(s)}{1 + G(s)} = \frac{\frac{s^2 + (k-6)s + 12}{s^2(s^2 + 6s + 12)}}{1 + \frac{s^2 + (k-6)s + 12}{s^2(s^2 + 6s + 12)}}$$

$$= \frac{s^2 + (k-6)s + 12}{s^2(s^2 + 6s + 12) + s^2 + (k-6)s + 12}$$

$$= \frac{s^2+(k-6)s+12}{s^4+6s^3+13s^2+(k-6)s+12} = \frac{R(s)}{q(s)} \qquad (7)$$

The gains boundary for stability is:

$$6 < k < 84 \qquad (8)$$

Now, we choose a k=30, hence:

$$G(s) = \frac{s^2 + 24s + 12}{s^2(s^2 + 6s + 12)} \qquad (9)$$

And by applying the PID controller [61]:

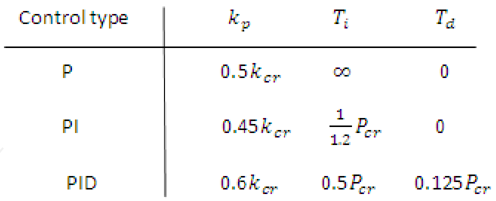
$$G(s) = G_c(s).G(s)$$

$$= k_p\left(1 + \frac{1}{T_i s} + T_d s\right).\left(\frac{s^2 + 24s + 12}{s^2(s^2 + 6s + 12)}\right) \qquad (10)$$

And the feedback transfer function is:

$$T(s) = \frac{G^{'}(s)}{1+G^{'}(s)} = \frac{k_p(T_i s)[s^2+24s+12]+k_p[s^2+24s+12]+k_p(T_iT_d)s^2[s^2+24s+12]}{(T_i s)(s^2(s^2+6s+12))+k_p(T_i s)[s^2+24s+12]+k_p[s^2+24s+12]} \qquad (11)$$

And by using Ziegler-Nichole's method [58] to find T_d T_i , k_p we have:



Control type	k_p	T_i	T_d
P	$0.5k_{cr}$	∞	0
PI	$0.45k_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.6k_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

Figure 4: Ziegler - Nichol's method

Now by setting T_i to ∞ and T_d to zero we will have:

$$\lim_{T_i\to\infty} T(s) = \frac{k_p\,(s^2 + 24s + 12)}{s^2(s^2 + 6s + 12) + k_p\,(s^2 + 24s + 12)} = \frac{R(s)}{q(s)} \qquad (12)$$

Which results $0 < k_p < 3$. So, replace s to jω and solve problem with supposing that k_p is one.

$$q(s) = s^4 + 6s^3 + 13s^2 + 24\,s + 12 = 0 \qquad (13)$$

$$q(s) = \omega^4 - 6j\omega^3 - 13\omega^2 + 24\,j\omega + 12 = 0$$

$$\omega = 3.46 \quad ,P_{cr} = \frac{2\pi}{\omega}, T_i = 0.5P_{cr}, T_d = 0.125P_{cr}$$

$$k_p = 1, T_i = 1.57\,, T_d = 0.39$$

These achieved values are considered as primitive values. In addition, considering fuzzy logic [59] [60] and taking output of the system for three primitive values, calculate desired values for T_d , T_i , k_p. Hence, in the fuzzy controller calculate the values of k_p, T_d , , T_i through Ziegler-Nichole's method.

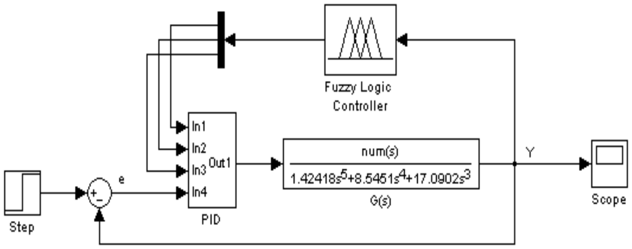


Figure 5: represent the Hybrid fuzzy- PID controller

In figure 5, gain function of system follows it:

$$G(s) = \frac{s^2 + 24s + 12}{s^2(s^2 + 6s + 12)} \qquad (14)$$

$$G_c(s) = \left(1 + \frac{1}{1.57s} + 0.39s\right)$$

$$G'(s) = G(s).G_c(s) = \frac{0.39\, s^4 + 10.39\, s^3 + 29.68\, s^2 + 36\, s + 12}{s^3(s^2 + 6s + 12)}$$

Figure 6, shows the PID subsystem of hybrid controller:

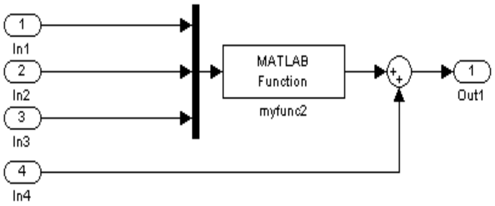


Figure 6: PID subsystem of hybrid controller

In this subsystem, IN3, IN2, IN1's inputs are parameters of control function and IN4 is the error of input function. The overall algorithm of this system is:

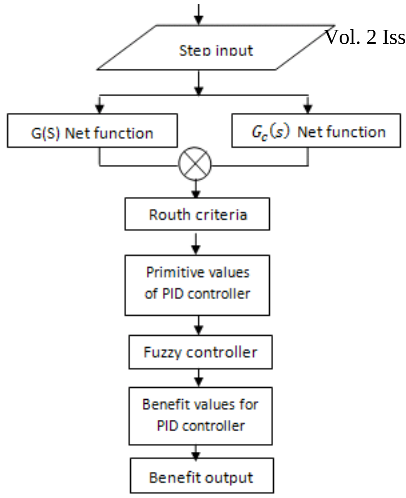


Figure 7: algorithm of hybrid controller

At the first time, here, subsystem sets up with step's input and primitive values of T_d T_i , k_p. Subsystem imposes these values to controller without that effect upon function inputs. Thus, after first output, fuzzy controller sets up. In the fuzzy controller, we have rules and membership function that calculate the desired values of T_d T_i , k_p . Finally, these values are applied to PID controller that produce the desired output and we achieve a stable controllable system. The membership functions of fuzzy controller are shown in figure 8.

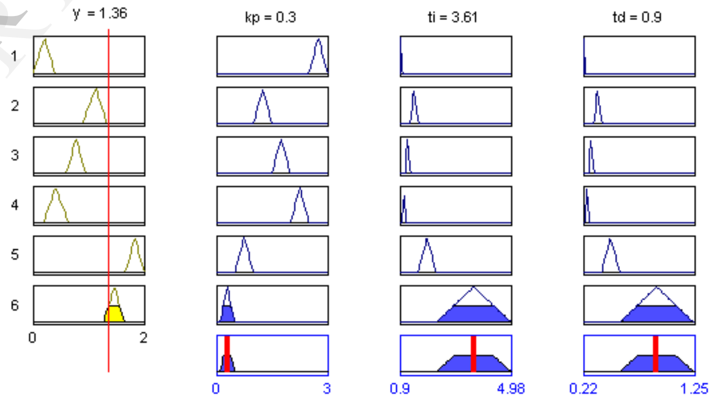


Figure 8: membership function of fuzzy controller

Output surface of fuzzy controller is shown in figure8.

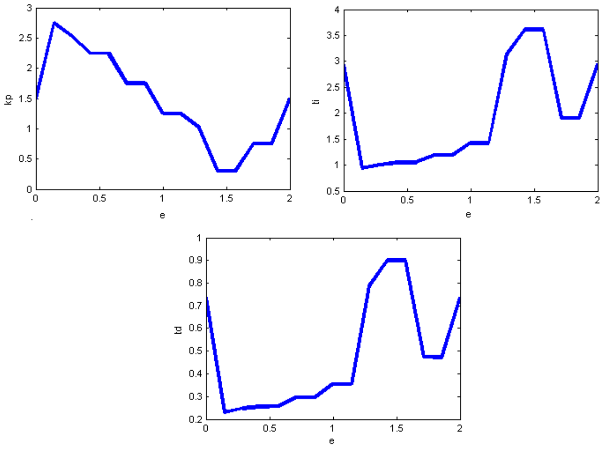


Figure 9: output surface of fuzzy membership function

The Controller in Figure 5 was offered for just one robot. For two cooperative robot manipulators the controller is extended such as Figure 10. The trajectory tracking of the system and angles for both robot manipulators is shown in Figure 10. In Figure 10, teta1 is first robot arm that shows the angle of motion (Arm1) and in the second arm teta2 denotes the angle of motion (Arm2) in two cooperative robot manipulators system.

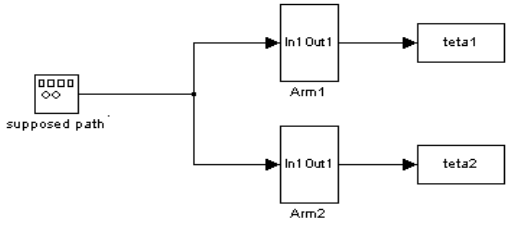


Figure 10: Hybrid controller with two cooperate arm robot

In Figure 10, in each of Arm1, Arm2 sections is designed a controller based on the controller is designed in Figure 5. Arm motion for these two partners in this cooperate system from a manufacturer to produce a signal in SIMULINK toolbar supposed path we use and the type of robot motion and change their angle of items together for transmission beam we studied. The resulting output motion for two-arm robot carrying beam with a supposed path is like Figure 11.

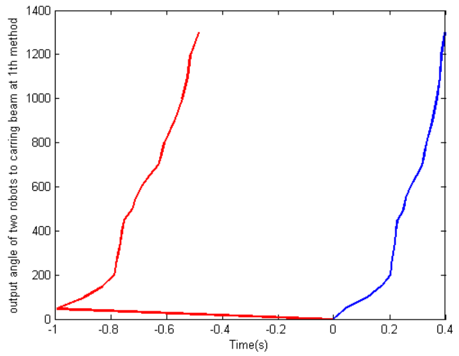


Figure 11: supposed path for transition beam by two cooperate robots in 1th method

To analyze the performance of these two robot control system controller combination, the two other methods are used to compare. The first method is a conventional PID controller which applied Ziegler – Nichol's to derive their parameters. In this way, the network function G (s) with alternative methods Ziegler – Nichol's. The structure of the controller for one robot manipulator with three degrees of freedom is shown in Figure 12. ZN subsystems from multiple user-defined function parameter Returns the value uses a PID controller. These functions follow Ziegler – Nichol's method.

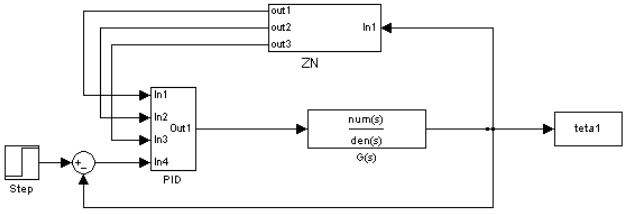


Figure 12: Ziegler Nichol's method in hybrid controller for one robot

Now, in Figure 13 the proposed controller is extended for two cooperative robot manipulators system to handle beam. So, a general form of controller is formed in Figure 13.

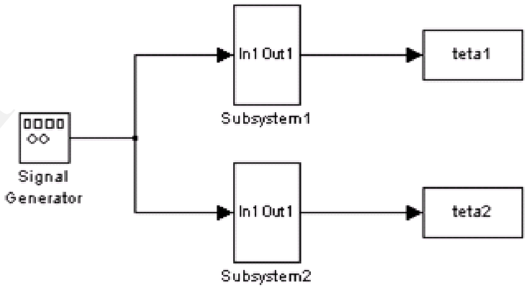


Figure 13: Ziegler Nichol's in hybrid controller for two cooperative robots

Here, by using the SIMULINK tool bar, we used a signal path generator to move cooperative robot manipulators along the road. It should be noted that this supposed path created same for all methods which are expressed in this paper.

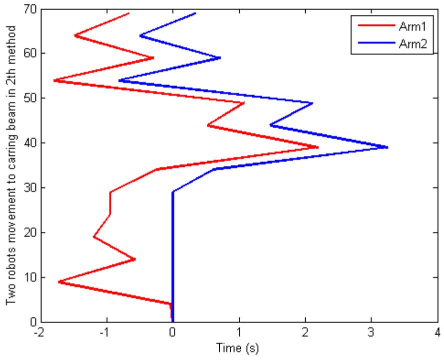


Figure 14: supposed path for transition beam with two cooperate robot with Ziegler Nichol's method in Hybrid controller

The third method used the conventional fuzzy controller, as a unique function for the gain function. The inputs of fuzzy controller are error function and derived of error function. The output of controller is angular position of the beam. This controller is shown on figure 15.

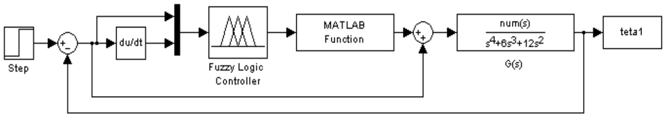


Figure 15 : the fuzzy controller for G(s) function

Fuzzy rules which are defined to obtain linguistic fuzzy controller output (gain) is presented in Table 1.

Table 1: Fuzzy rules for fuzzy controller system presented in the third method (fuzzy controller automatically unique)

ė(t) / e(t)	NB	NM	NS	PS	PM	PB
NB		NB	NM			PS
NM				NS		
NS	NM					
PS		NS			PM	
PM						PB
PB	PS			PB		

The fuzzy membership functions for fuzzy controller are shown in Figure 16.

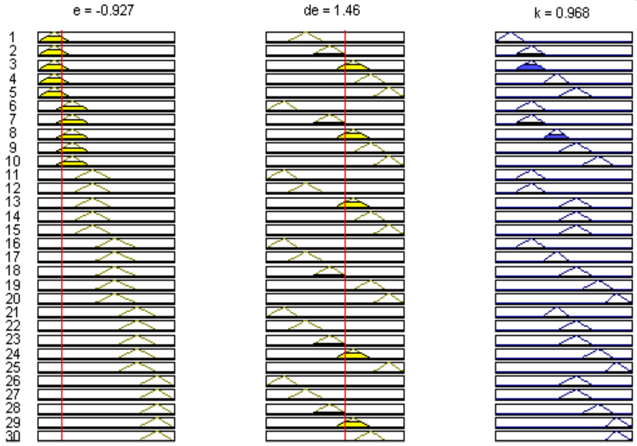


Figure 16: Membership functions of fuzzy controller in the third method

The Level of fuzzy membership functions' output for fuzzy controller with variable $k_1$expressed in Figure 17. This output level for k_1 is obtained by using e and ė.

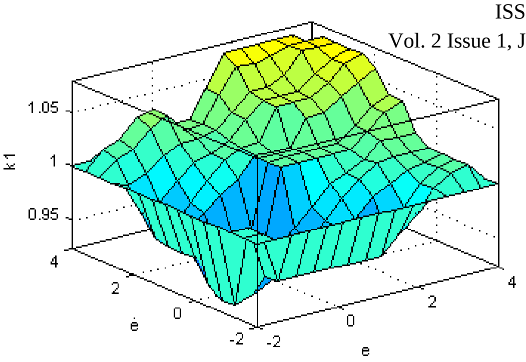


Figure 17: Output level for k1 values at fuzzy controller in the third method

The controller which is proposed in Figure 15 is for just one single robot manipulator. For two cooperative manipulators like other methods, this controller is extended in Figure 18. As previous methods, is applied SIMULINK tool bar to generate supposed path for two cooperative robot manipulators. With the help of this supposed path, type of motion of these two partner robots in this way will also analyzed.

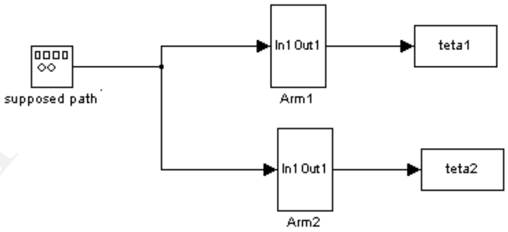


Figure 18: Third extended method for two robot colleague

Trajectory tracking produced in the third method for two robot manipulators in Figure19.

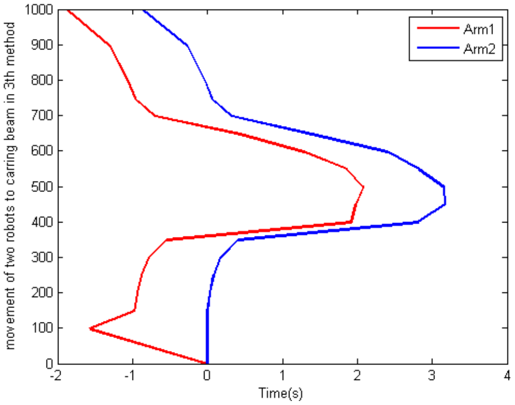


Figure 19: supposed path for the robot to move the two partners, the third method for carrying beam (Fuzzy)

In the each of the paths which are produced by the three methods are shown in figures 11, 14, 19, emphasis on the distance between two robots in the beam along the way during transfer is supposed.

In this case, if the distance between the robots during motion is constant and two cooperative robot manipulators try to keep the distance between each other, it will be the best trajectory tracking. But if the distance of two cooperative robot manipulators is collision will be happened and the beam will be broken. Also, if this is long distance, may be the beam will be out of the control and will be fall down and break. In the simulation section the behavior of the three methods will be analyzed.

3.Simulation

In this paper, two 3 DOF robot manipulators to handle a very lightweight beam contain highly sensitive material is introduced. In this paper, controller for controlling the angle beam to the track surface was introduced. The hybrid Controller is combination of fuzzy controller and PID controller. In addition, to comparison is used two other methods, the conventional PID method with Ziegler- Nichol's method and the conventional fuzzy method.

Proposed controller for two robot manipulators to handle an object in the previous section is simulated with the software Matlab 7.6.0 (R2008a) and toolbox SIMULINK. As in the previous section was presented for three supposed paths system for transferring a light beam by two-robot system, was considered. Examining paths created by the system in three ways in figures 11, 14, 19, three ways how this system has been shown. Production paths, which in figures 11, 14, 19 can be observed, we consider, within each of the lines has been produced that shows the distance of two robot lines, beam are being transported. What these lines have the same distance relative to each other regularly and are more acceptable method would be used. If the linear distance is less than the original mode, robots have to move together and may be, is otherwise established that the two robots are close to each other so that critical beam break. If the distance is more than usual, Robot control beam out and falls on the ground that none of these cases we consider is. Such as beam, containing important and sensitive material is placed in a beam in a dangerous position, may provide a numerous problems. In this paper we try, we can choose which way to move very regular system and for our system and our environment, the problems did the trick.

Moreover, many new methods of expression are today, the ecosystem, can carry the frequency loss that creates an environment for future generations to be restive. In the first method, a combination controller, fuzzy controller consists of controller with PID, control system introduced, was expressed. Direction in this system, Figure 11 and Figure 20 is, robots move away from each other along the way, when the transfer beam, that will be given. As can be seen, roughly the distance between the robots over time, is constant. It should be noted that the distance between lines is not our consideration. Here, only, a width of two lines that show the distance the robot is peer, attention will.

In the second method, the same controller in the first method was used. the only difference here that the first method, the PID controller parameters for the production of fuzzy controller was used but the second method, the parameters for the production controller PID, Ziegler-Nichol's method was used. Path controller system introduced in the second method is in Figure 14 and Figure 21 is production lines which indicate the space between two robots, while moving along the way is the second method, is shown. In the Figure22 is shown lines that are different distances, marked in red have been specified. As can be seen in the second method, the location where with No. 1 is shown, robots very close together and in place No. 2, robots are very far apart.

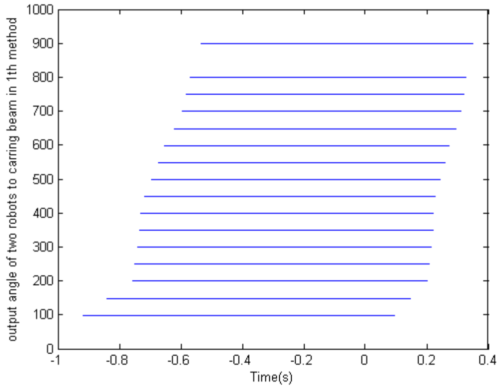


Figure 20: motion lines of two robots at 1th method

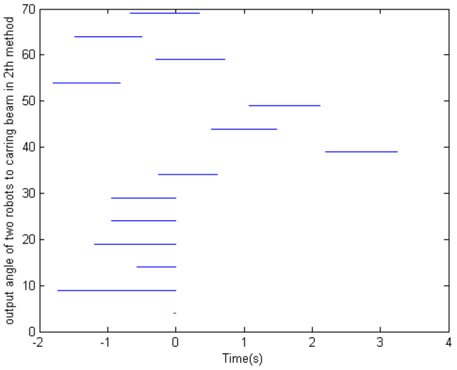


Figure 21: motion lines of two robots at 2th method

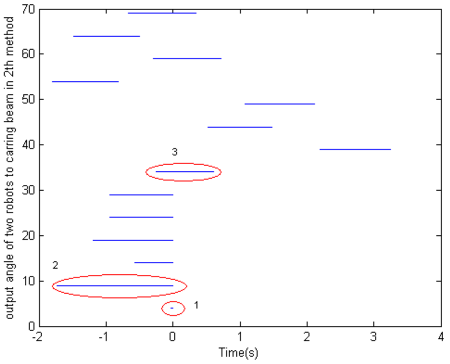


Figure 22: motion lines of two robots at 2th method

In the third method for controlling network system function provided, the fuzzy controller was used. In this way, other than PID controller is not used. As can be seen in this way also, from many lines is not constant, but compared to the second reaction is better, but towards the first method that has been argued, is not good. Path controller system introduced in the third method is in the figure 19 and in the figure 23, which represents production lines within two robots, while moving along the way is the third method, is shown. Figure 24, lines with different distances are marked in red have been specified. As can be seen in the third method, in a place with number 1 is shown in locations is far apart, and No. 2, robots are closer together.

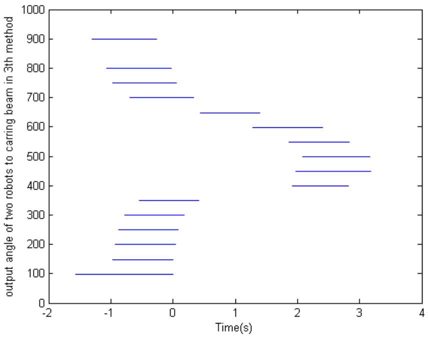


Figure 23: motion lines of two robots in 3th method

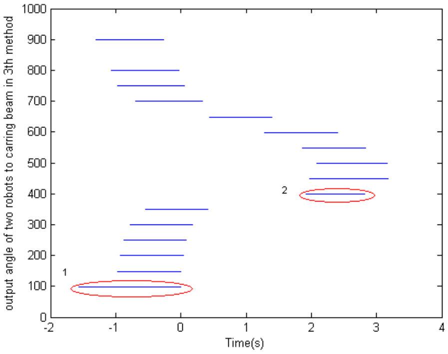


Figure 24: motion lines of two robots in 3th method

Analysis results in the three presented controller, as summarized in Table 2 is expressed. As can be seen in the table2. In the first method for the control system presented, the combination of fuzzy controller and PID controller was used, simulation time than other methods is high, but the distance between two robots when transferring sensitive beam along the way are very stable and more regular is. In the second approach, which combined the Ziegler-Nichol's method with PID controller was used, simulation time is very low, but no space between two robots is fixed. The third technique that only fuzzy controller for control system is used, the average simulation time and the distance between robots, while crossing the road bars is average, but due to constant errors cannot be sure this was. So the first method of reliability is higher.

Table 2: results of comparing three methods

Methods	Reliability	Robot deviation	Simulation time
Hybrid controller of fuzzy and PID controllers	high	little	High
PID controller with Ziegler-Nichol's method	low	high	low
Fuzzy controller	average	average	average

4.Conclusion

In this paper, a two cooperative robot manipulators system for handling lightweight beam which is contains highly sensitive material is presented. In this system is only considered angular measurement for trajectory tracking. To face with uncertainties a combination controller consists of PID controller and fuzzy controller for control system is offered. In the hybrid controller, PID controller is employed for motion control and fuzzy controller is used for the estimate parameters of PID controller. To comparison, the proposed controller compares with two other controllers, conventional PID controller with Ziegler-Nichol's method and conventional fuzzy controller on the system with two 3-DOF robot manipulators. Simulation results show the hybrid controller has better performance than two others to handle a hypersensitive beam with two cooperative manipulators.

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