Dynamics and Control Structure for NPID Controller

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Abstract. Designing a non-linear controller has always been a very daunting job for researchers and control engineers. The robotic manipulators have multiple inputs and multiple outputs. In this paper, we are talking about two link manipulators. A comprehensive explanation of dynamics and the control structure of the NPID controller have been provided to the industries by reducing the workforce with the help of automation. This controller is a combination of Proportional Integral and Derivative Controller and has a nonlinear factor that is multiplying with the integral controller, and it was further concluded that the NPID controller was the best among the others. This controller is used in various important fields such as welding, underwater robots, industry, painting, spot welding and many more.

Keywords—Nonlinear PI Controller, PID Controller, Robotic manipulator

1. Introduction

As robotics and automation are now being used in almost every field, the rapid growth in rising technology as well as in the growing population has benefited the robotics market. A robot is essentially a programmable controller that could be operated by coding or controller[1] in this paper we discussed and designed the dynamic model and the structure of a non-linear PID controller. In this paper we discussed and established the dynamic model and the structure of a non-linear PID Controller. By involving robot lives and work, a robot can fully transform a repeat task in a very precise way, especially some tasks that are difficult for humanity are easily performed by a robot. The fusion of several branches together is robotics[2][3]. For the control of a manipulator, computer engineering and electronics engineering may be used while the output of the robot comes from mechanical engineering. A non-linear controller is one that is a time variant in nature and can easily control the non-linear robotic manipulator[4]. There by the help of non-linear differential equation, the manipulator system is drawn as the ties increased, so the complexity increased, so it is a very trivial task to design such a controller that could control highly non-linear controller as well as provide optimal results[5][6]. Uncertain systems are operated by adaptive controllers, a device capability that essentially depends on the controller through which the main task of a non-linear controller has been attached is to provide details about the current system state and also to compare the current output system with the desired performance. In order to get the desired performance, the gains are precisely calibrated with the aid of the algorithms. The technique has been used before.
2. Literature Survey

Robot control has always been a challenging job for engineers since 1950, when the layout of this controller is very simple to design and its implementation is very inexact, this controller is very economical in terms of cost[7-9], to control the nonlinear and complex manipulator systems PID came to light. But it did not yield flawless results and was unable to deal with the nonlinearities and complexity to solve these problems. In 1960, another technique came into existence. The name of this technique was classical adaptive control technique. All these methods are largely based on the manipulator system's dynamic model, which also gives us the best way to deal with nonlinearities and complexity[10-12].But as it has been said that nothing is perfect, so there were some drawbacks and disadvantages in these control techniques as it needs precise mathematical model to produce perfect results, it is also difficult for scheduling design to handle the broad operating point[13]. So a new technique was investigated to handle those systems that are poorly dynamically analysed.so to handled those system who are being poorly dynamically analysed a new technique was investigated that is artificial intelligence which was combined with these classic control techniques[14]after this to enhance the techniques and to make the system more intelligent fuzzy logic controller (FLC) and artificial neural network and also the combination of the both that is neuro-fuzzy technique these merging of controllers give very good result in increasing the capabilities of sliding mode controller (SMC)[15].Fuzzy logic controller provides almost accurate results for uncertain system zadeh has proposed this fuzzy logic which is not just restricted between true or false. inspite of that help us to deal with the probabilities that lies between atmost true and atmost false[16]after this fuzzy logic controller came which was proposed by Mamdani[17] as the years passes the elaboration in the work of fuzzy logic controller was kept on increasing as the work related to fuzzy was further carried out by Graham[18] Graham and Newell[19,20]when these classic control methods combine with artificial intelligence (AI) and neuro fuzzy logic this gives the control engineering a new way and a new trend and just from control engineering it is switched to robotics control and automation[21] these fusion technique are very much helpful in controlling almost all the fields like chemical,food,textile and these controllers are playing a vital role in controlling the robotics [22] a simple human hand in terms of robots is known as robotic manipulator they are very much nonlinear and multi input multi output links of the manipulator can be minimum when but the links are being kept on increasing depending on the specific task for which the controller has been designed with the help of controllers we are able to reach those locations which are not easily accessible welding and assembling[23] Intelligent techniques were arrive in 1990’s which has overcame the drawbacks of classical and traditional PID controller and the combination of PID controller with fuzzy logic completely resolve all the drawbacks of PID and Fuzzy controller and also increase the advantages as a whole and as a result it has been noticed that by adding both the techniques robust system can be formed [24,25].control system which are based on fuzzy logic are in detail analysed by wang and kwok [26] then they themselves suggest the combination of fuzzy pd and fuzzy I controller .further by making a small improvement in the fuzzy PI controller Li and Gatland [27] proposed a fuzzy three term controller.
### 3. Plant Description

For a rigid robotic manipulator system having two links and a payload A mathematical model was given by Lin (2007) [28] which is used as a plant in this work. The description of the mathematical equations is been given below

\[
\begin{bmatrix}
S_{11} & S_{12} \\ S_{21} & S_{22}
\end{bmatrix}
\begin{bmatrix}
\ddot{\theta}_{11} \\ \ddot{\theta}_{22}
\end{bmatrix} +
\begin{bmatrix}
P_{11} \\ P_{21}
\end{bmatrix} +
\begin{bmatrix}
f_{r1} \\ f_{r2}
\end{bmatrix} +
\begin{bmatrix}
f_{n1p} \\ f_{n2p}
\end{bmatrix} =
\begin{bmatrix}
\tau_{f1p} \\ \tau_{f2p}
\end{bmatrix}
\]

Where

\[
S_{11} = I_{1p} + I_{1c} + m_{11}l_{c1}^2 + m_{22}l_{c2}^2 + 2m_{22}l_{11}l_{c2} \cos \theta_{22} + m_{vp}l_{11}^2 + m_{vp}l_{22}^2 + 2m_{vp}l_{11}l_{22} \cos \theta_{22}
\]

\[
(1)
\]

\[
S_{12} = I_{2p} + m_{22}l_{c2}^2 + m_{22}l_{11}l_{c2} \cos \theta_{22} + m_{vp}l_{22}^2 + m_{vp}l_{11}l_{22} \cos \theta_{22}
\]

\[
(2)
\]

\[
S_{21} = S_{12}
\]

\[
(3)
\]

\[
S_{22} = I_{2p} + m_{22}l_{c2}^2 + m_{vp}l_{22}^2
\]

\[
(4)
\]

\[
P_{11} = -m_{22}l_{11}l_{c2}(2\ddot{\theta}_{11} + \dot{\theta}_{22}) \dot{\theta}_{22} \sin \theta_{22} - m_{vp}l_{11}l_{22} \left(2\ddot{\theta}_{11} + \dot{\theta}_{22}\right) \dot{\theta}_{22} \sin \theta_{22}
\]

\[
(5)
\]

\[
P_{21} = m_{22}l_{11}\ddot{\theta}_{11}l_{c2} \sin \theta_{22} + m_{vp}l_{11}\ddot{\theta}_{11}l_{22} \sin \theta_{22}
\]

\[
(6)
\]

\[
f_{r1} = b_{1vp} \dot{\theta}_{11}
\]

\[
(7)
\]

\[
f_{r2} = b_{2vp} \dot{\theta}_{22}
\]

\[
(8)
\]

\[
f_{n1p} = m_{11}l_{c1}g \cos \theta_{11}
\]

\[
+ m_{22}g(l_{c2} \cos(\theta_{11} + \theta_{22})
\]

\[
+ l_{11} \cos \theta_{11} + m_{vp}g(l_{22} \cos(\theta_{11} + \theta_{22}) + l_{11} \cos \theta_{11}
\]

\[
(9)
\]

\[
f_{n2p} = m_{22}l_{c2}g \cos(\theta_{11} + \theta_{22}) + m_{vp}l_{22}g \cos(\theta_{11} + \theta_{22})
\]

\[
(10)
\]

Final equations

\[
\ddot{\theta}_{11} = \frac{\tau_{f1p} - f_{n1p} - f_{r1} - P_{11} - S_{12} \dddot{\theta}_{22}}{S_{11}}
\]

\[
(11)
\]

\[
\dddot{\theta}_{22} = \frac{(\tau_{f2p} - f_{n2p} - f_{r2} - P_{21} - S_{12} \ddot{\theta}_{11})}{S_{22}}
\]

\[
(12)
\]

### 4. NPID Controller
Currently Linear controllers are being used very frequently for controlling of robotic manipulator. Or very few nonlinear controller might be designed. This controller offers a completely different approach for dealing with the nonlinear model and also handles very well the slow time varying errors and various uncertain parameters. PI control is a form of feedback control. It provides a faster response time than I-only control due to the addition of the proportional action. It stops the system from fluctuating, and it is also able to return the system to its set point. This Proposed controller have various advantages over the traditional controllers like faster speed, more accuracy it also provides better stability to the system the PI controller combination help to fully removed the steady state error it has good transient response and is robust to handle nonlinearity's. The nonlinear controller is designed with the help of a time-varying nonlinear factor $\psi(t)$, The function of this controller is that it is multiplied with integral gain to change it in run time and to compensate all the uncertainty which appears automatically. It has been designed by a mathematical equation.

$$\psi(t) = \left[1 - \exp\left(-\left(ae^2(t) + br^2(t)\right)\right)\right]^2$$

Here, ‘e’ and ‘r’ are instantaneous error and derivative of error respectively. Constants ‘a’ and ‘b’ are the parameters for nonlinear control law. NPIC has a time-varying term $\psi(t)$ which multiplies with integral controller and thereby reduces the integral action when $\psi(t)$ reduces. The reduction in $\psi(t)$ happens when both error and rate of change are approaching zero, as realized by nonlinear control law. The reduction in integral action puts a brake on the controller output so as to restrict process variable to jump across set point when the process is exhibiting limit cycles. This action further removes limit cycles from the process variable and the controller output as well. This whole controller can be attached to the dynamic model of robotic manipulator which can be treated as a plant and in order to check the correctness of the controller sine wave can be given at the input. This waveform is best suited for trajectory tracking planning of manipulator as the manipulator trajectory path is same as that of sine wave and further simulation can be run on MATLAB/SIMULINK.

5. Results
Fig 2. Set Point Tracking

The above figure shows the sine wave trajectory tracking here sine wave has been used as a reference wave and we are able to track the reference wave by using the NPID controller and we are able to achieve the desired result a nonlinear element has been multiplied by the integral controller making the entire controller nonlinear. As this controller manages two connection manipulators, the graph here shows the trajectories of the valued ties. The blue colour line represents the connection 1, while the brown colour line represents the connection 2, all the trajectories form the sine wave shape.

6. Conclusion

In this work, the dynamic model of the NPID controller was analysed and the structure of the controller was drawn using Simulink. This modelled controller is able to track the sine wave, that this wave was given as a reference wave and with the help of the controller we are able to track the reference wave and can achieve our desired results. The main benefit of the NPID controller is that it has the good characteristics of all three controllers, and this controller can operate very well with pneumatic controllers due to the non-linear aspect that makes it even more robust.

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