Using Different Controlling Methods on a 3-DOF Arm Robot

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***Abstract*—Control engineering is one subject which is perceived as being the most theoretical and most difficult to understand. In our project we modeled a 3-DOF arm to move in desired trajectory in joint space. Three controllers have been designed to follow the desired profile, including PID controller, adaptive controller, and impedance controller. Then we use SimMechanics to acquire the simulated dynamics feedback of the arm to test the performance of these 3 controllers. Our testing goal is that making the joint position get as close as possible to the desired position .**

I. Introduction

Robot control always has been the enter among the subjects of robotics. Both academy and industry put attention on this subject.In this project, we simply implement the basics of robot control in joint space, which make the robot follow a desired trajectory. There are 3 different controllers used, PID controller, adaptive controller and impedance controller. Each controller has different properties which enable them suitable for some certain tasks.

The rest of the paper construction is as follows. The second chapter stated the related work of robot joint space controllers. The third part stated the problem of robot joint control. The fourth part introduced the environment of our simulations. The fifth part presented different controllers as well as the simulation results analysis.

II. Related Work

Despite the traditional PID control, which is the old technique from 1922 Nicholas Minorsky presented a clear analysis of the control law with 3 terms [9].

Started in the mid 80s, Robot manipulator control is a subject extensive researched. Adaptive control of rigid body is one of the successful control theories, by linearity in the inertia parameters and the skew-symmetry property of the robot inertia matrix [7].

III. Problem Statement

The problem of robot control is the root of robotics. Every motion carried by a robot must be continuous or discrete trajectory in joint space, where a set of law is required to guarantee the result of the control result which means that the true joint angle must converge to the desired one given the presence of the discrepancy of the model from real robot, sensor noise and etc.

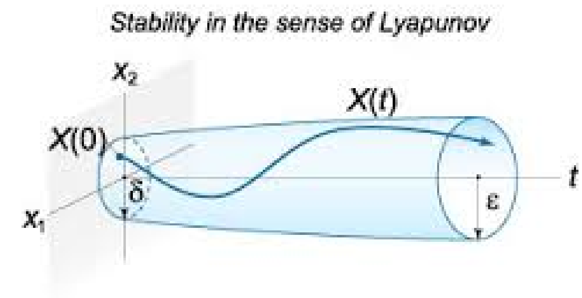


Fig. 1. Lyapunov stability

Robot dynamics is to model the robot with nonlinear second-order ordinary differential equation derived from Newton mechanics or Euler-Lagrangian mechanics, which is crucial to joint space control. Once the robot dynamics model is provided, force of each joint could be calculated in closed form. Many aspects should be taken into account of this dynamics model, including the inertial of each link, gravity compensation.

IV. Environment

In order to keep the scope of the project from getting too large, we construct a 3 DOF robot arm in SimMechanics. The details of the design of the arm and simulation are discussed below.

A. Mechanical

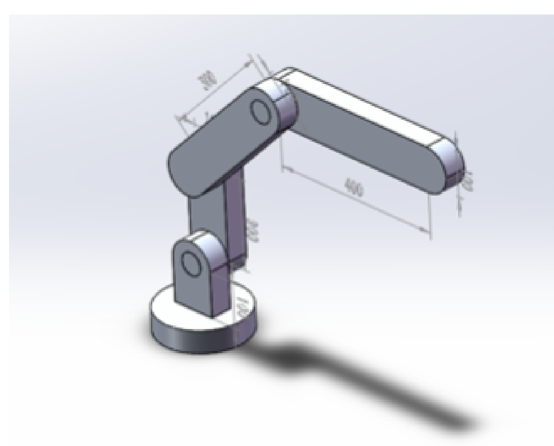


Fig. 2. The arm model picture in Solidworks.

For simplicity of design and kinematics, the robot arm consist of 3 revolute joint, with equal joint length between each joint, shown in Fig.2. From the standpoint of control, the controller would work the same regardless of the exact construction of the manipulator, on the condition that the robot dynamics is known and the controller is Lyapunov stable.

B. Simulation

We use SimMechanics to generate dynamics feedback, this is an on-line feedback. We design our physical model in Solidworks, setup all the material properties and then import them into SimMechanics. After that, we can get the simulated value from the model.

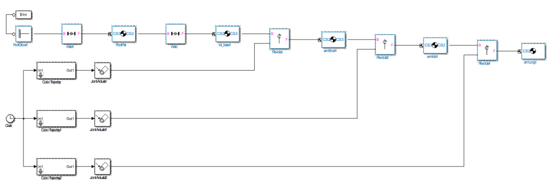


Fig. 3. The Arm Model in Simulink.

The Solidworks files of the Arm model could be directly imported into Simulink if designed properly. We use the imported Simulink arm model as our plant part in the simulation. The raw arm model in Simulink is shown in the fig. 3

V. Methodology

A. PID Control

The PID controller is the most common form of feedback. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. In process control today, more than 95% of the control loops are of PID type, most loops are actually PI control.

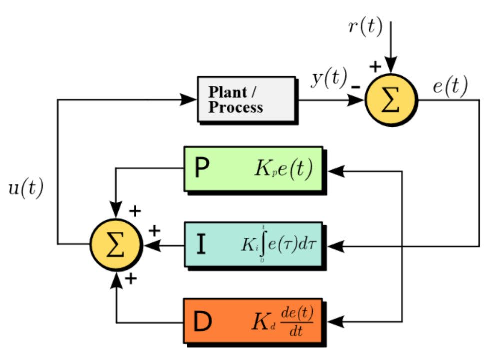


Fig. 4. The PID Control Block

1) Design: We make the angle of each joint move from 0 deg to 10 deg in 1 second with the angular velocity of 10 deg/sec and applied PID controller to each joint. The PID block diagram is shown in Fig.4

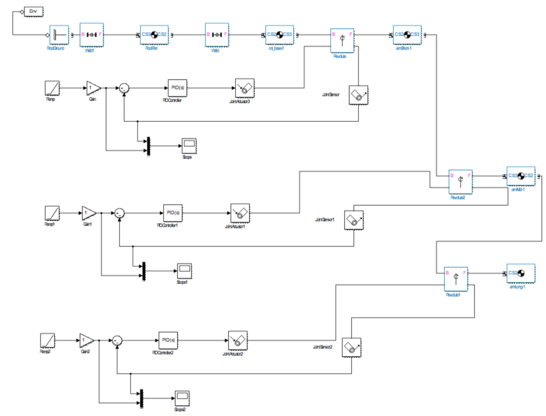
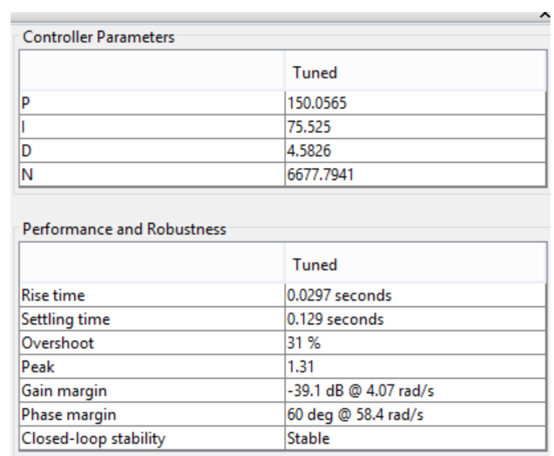


Fig. 5. Arm model with PID Controllers.

Using the PID block in Simulink we build the Simulink model with PID controller of each joint. The model is shown in Fig.5

We tune the parameters of each block to a have better performance, the configurations are shown as follow:



Controller Parameters

	Tuned
P	150.0565
I	75.525
D	4.5826
N	6677.7941

Performance and Robustness

	Tuned
Rise time	0.0297 seconds
Settling time	0.129 seconds
Overshoot	31 %
Peak	1.31
Gain margin	-39.1 dB @ 4.07 rad/s
Phase margin	60 deg @ 58.4 rad/s
Closed-loop stability	Stable

Fig. 6. The PID Parameters Configuration of Joint 1.

2) Results: Given a desired angle from 0 degree to 10 degree and angular velocity of 10 degree per second, we can have the desired position and real position as follows.

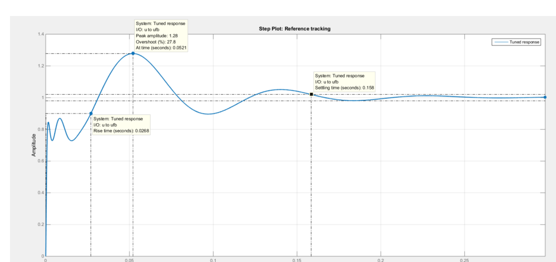


Fig. 7. The Step Response of Joint 1.

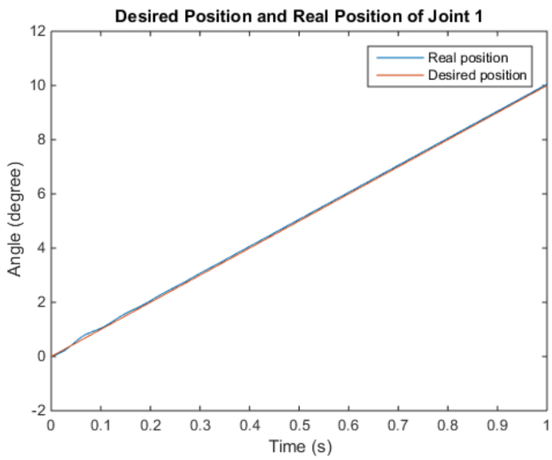


Fig. 8. The Desired vs Actual Joint Angle over time of Joint 1.

B. Adaptive Control

Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary,or are initially uncertain. [2] An adaptive control system measures a certain performance index (IP) of the control system using the inputs, the states, the outputs and the known disturbances.

From the comparison of the measured performance index and a set of given ones, the adaptation mechanism modifies the parameters of the adjustable controller and/or generates an auxiliary control in order to maintain the performance index of the control system close to the set of given ones.

For example, a motor may changes its stiffness value during the run-time or a planes gas tank may reduce the planes whole weight during a flight. As we see, in those cases the plants system parameters are changing along with time and that is when we want to use an adaptive controller to compensate this.

1) Design: In this project, we design a Simulink model that uses adaptive control to control a 3 DOF arm model. The system has following parts:

- An Input model
- A Sub Controller model
- A Reference model
- A Plant model
- An Adaptive adjustment model
- Several outputs

2) Reference Model: The reference model is how you want your system behavior is. It should carry a transfer function changing along with time. In my understanding, this will be seen as the desired value of your system output and then you compare it with the actual value from dynamics to calculate the error. In this simple case, we have a very raw reference model that the output is just the same as the input.

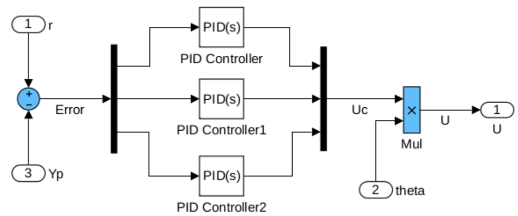


Fig. 9. Sub-PID Controller of Adaptive Control.

3) Sub Controller Model: We have three PID controllers as the sub-control system to control our three joints. We are using the direct adaptive control so the adjustment value coming from the adaptive controller will directly affect the PID controllers output. This is shown in the Fig.9 as theta(2).

We can conclude that

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + F\dot{q} + g(q) = u$$

under the control law

$$u = Y(q,\dot{q},\dot{q}_r,\ddot{q}_r)\hat{\theta} + K_D(\dot{\tilde{q}}+\Lambda\tilde{q})$$

and the parameter adaptive law

$$\dot{\hat{\theta}} = K_\theta^{-1} Y^T(q,\dot{q},\dot{q}_r,\ddot{q}_r)[\dot{\tilde{q}}+\Lambda\tilde{q}]$$

asymptotically converge to $\sigma = 0$ and $\tilde{q} = 0$.

Fig. 10. The Adaptive Control Law.

4) Adaptive Mechanism: We follow the note reference [3] in Fig.10, we design a simulation diagram as shown in Fig.11. The adaptive results are given by $Y * \hat{\theta}$, which is the error between Y_{plant} and $Y_{reference}$. Since it is an angular speed, we integrate it to get an angle and pass it to the sub-controller.

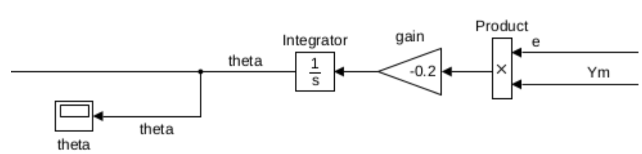


Fig. 11. Adaptive Controller in Simulink.

5) Results: In the adaptive model, we have put a gain value as the learning rate. This will give a weight info to the system that shows how fast should the adaptive mechanism react to the error.

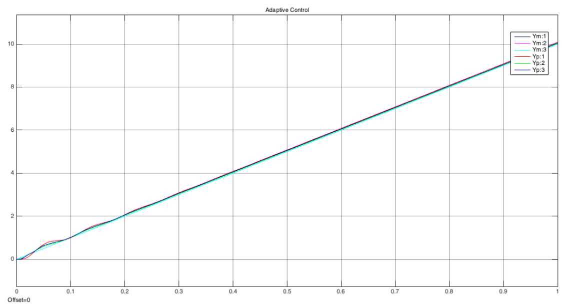


Fig. 12. Joints Position over time with Learning rate = 0.01

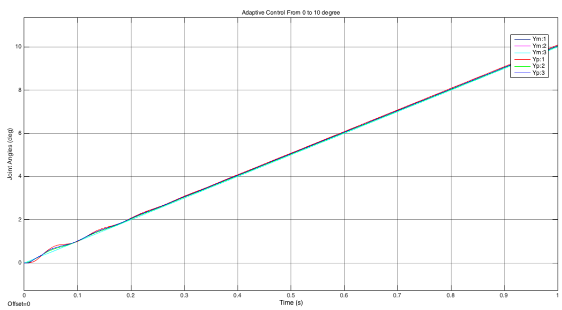


Fig. 13. Joints Position over time with Learning rate = 0.1

We run the system with a ramp source(slope = 10) to test. As shown in the figure, the actual values are following the desired values. We tune the PID parameters and get a reduced overshot range as well as make it converge at the end. In Fig.12 and Fig.13, Y_m is the desired value and Y_p is the actual output value, we change the learning rate to 0.1 and 0.01 to compare the results; however the results are not having big differences.

C. Impedance Control

Impedance control is an approach to the control of dynamic interaction between a manipulator and its environment. This type of control is suitable for environment interaction and object manipulation. The key theory behind the method is to treat the environment as an admittance and the manipulator as an impedance.

In the most common case in which the environment is an admittance (e.g. a mass, possibly kinematic constrained) that relation should be an impedance, a function, possibly nonlinear, dynamic, or even discontinuous, specifying the force produced in response to a motion imposed by the environment [1].

1) Design: Using the impedance control law from class

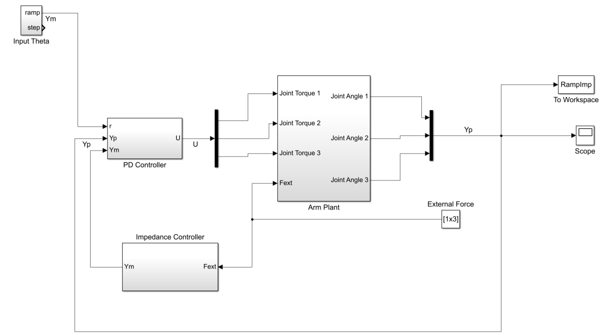


Fig. 14. Arm Model with Impedance Controller.

Use Simulink from Matlab, combined with the 3-DOF robot arm plant, we design a simulated model with impedance controller and an external force [10N, 0, 0] as shown in Fig.14

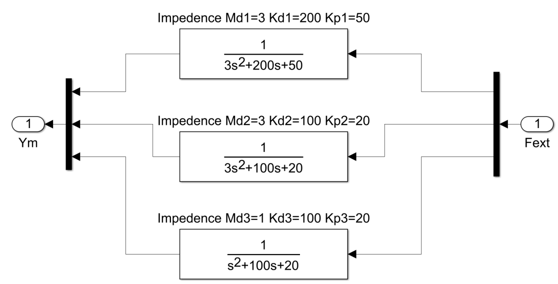


Fig. 15. The Impedance Controller Unit.

The controller owns a transfer function(s) inside the block, as shown in Fig.15

Joint	Md	Kd	Kp
1	3	200	50
2	3	100	20
3	2	100	20

We use the joint controller parameters as shown in the table above.

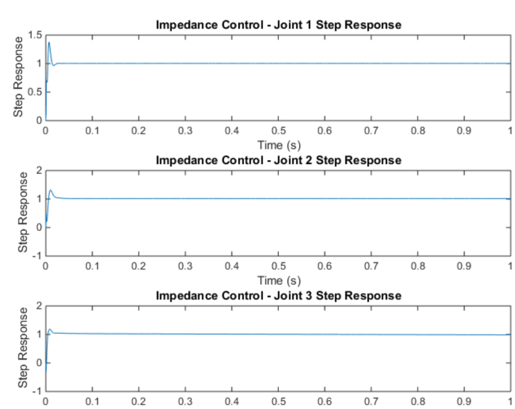


Fig. 16. Step response with impedance controller

2) Results: Fig.16 shows us the step response of each joint. From the result we can see that the rise time and settling time is small enough to make the system respond fast, all the overshoots are reasonable (under 40%), and all the systems are stable. The overshoot of Joint 1 is a little bit larger because this joint has to deal with more load.

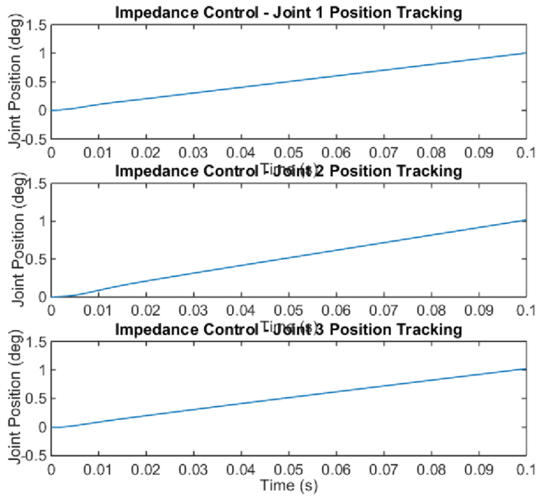


Fig. 17. Joint position tracking result

The joint position-tracking result in 0.1 second with angular velocity 10 deg/sec is shown in Fig.17. As we can see from the figure, all the joint angles are close enough to the desired angles. The three systems are all stable and have good performance. It is important to mention that the selected impedance value for a certain environment should be reconsidered when the manipulator is used in a significantly different environment for the sake of the precise control of the force exerted on the environment.

VI. Conclusion

This paper presents 3 types of controllers applied on a 3-DOF arm robot in Simulink. All the controllers do a good job following the desired joint trajectory.

In PID control, system has faster system response and less overshoot in the desired output, but the right P, I, and D coefficients are hard to get. And we may not want to apply the PID controller in very slow process such as home heating control system.

Compared with traditional control methods adaptive control could deal with complex systems that have unpredictable parameter deviations and uncertainties, but the system is sensitive to the value of the gains, which makes it harder to get the appropriate control coefficients to make the system overshoot small enough.

As for the impedance control, the objective is to establish a desired dynamical relationship between the end-effector position and the applied force so that it can be used in assembly tasks where excessive contact forces are required to be monitored and decreased. Also automatic excavators could be controlled by impedance controls to avoid excessive contact forces when the excavator may hit a rock.

VII. Discussion

How to evaluate the performance of a generated path is a critical problem. In our project, we focus on the control of the arm and only judge the performance by time consumed to generate a trajectory, which may not be suitable.

Acknowledgment

This paper is part of class project of robot control. The authors would like to thank Professor Padir who gave excellent lectures and great patience to his students.

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