Proceedings of ITC-CSCC 2000, Pusan, Korea

A Study on Implementation of Stable Interaction Control System

Yongteak Lim, Seungwoo Kim
Dept. of Electrical & Electrical Engineering, Soonchunhyang University
336-745 San 53-1, Eubnae-ri Sinchangmyun, Asan-si, Chungnam, Korea
Tel: +82-2-0418-530-1369, Fax: +82-2-0418-530-1373
E-mail: seungwo@asan.sch.ac.kr, nana@control.sch.ac.kr

Abstract: We introduce Adaptive Fuzzy Impedance Controller for position and force control when robot contact with environment. Because Robot and environment was always effected by nonlinear conditions, it need to deal with parameter's uncertainty. For solving this problem, it induced Fuzzy System in Impedance Control so fuzzy system is impedance's stiffness gain.
We apply adaptive fuzzy impedance controller in One-Link Robot System, it shows the good performance on desired position control and force control about contacting with arbitrarily environment.

1. Introduction

The each field of robots that they were used in industrial recently consists of working state that the most of robot hand contact with environment. For robot deal with these tasks like human, it needs force control exactly. Hence, the research of robot force control in home and foreign is very strong experimental trend and it is difficult to sets up experimental system which it needs a various techniques. Therefore, many researchers have only simulation situation.

In case of Robot-Hand or tool contact with environment, it is necessary to control force and position. This is an area of implementation algorithm, that is, and is referred such as compliance control, force control, hybrid (force/ position) control, impedance (admittance) control but we can find impedance control that shows a good results with position and force control combination scheme. However, impedance control didn't also exploit gain-tuning method for cope with robust control system in target system with dynamics uncertainty (gravity, friction and so on). Impedance controller needs adaptability for dealing with target system's parameters uncertainty. Therefore, this paper focuses that we suggests Adaptive Fuzzy Impedance Controller which it is using fuzzy inference engine with robust parameter uncertainty for stiffness gain on-line Tuning. Adaptive fuzzy impedance controller applies to One-Link Robot System through experiment and verifies the performance of algorithm.

For this experiment, we made One-link Robot System that controlled motor connected Torque Sensor left Shaft and load motor for offering contacted environment connected torque sensor's right shaft. Because it is free state that happen sampling rate, sensor noise in experimental. Hardware system used high-speed DSP Chip and we can prove Adaptive Fuzzy control algorithm

This paper consists of impedance controller scheme, adaptive fuzzy algorithm scheme using fuzzy logic, One-Link Robot System and hardware configuration using DSP chip, we analysis the performance while it move also environment sinusoidal velocity.

2. Impedance Controller

The control techniques discussed thus far are examples of position control methods that assume that the robot is moving freely in the workspace. It is also possible to design controllers that operate when the tool is in contact with the environment (Salisbury, 1980; Hogan, 1985; Asada and Slotine, 1986; Whitney, 1987; An et al., 1988). This is an area of active research and is referred to by terms such as compliance control, force control, hybrid control, and impedance control. In this section, we examine one specific approach for illustration purposes, namely, impedance control.

Each manipulation task has associated with it a set of natural constraints which are imposed on the robot by environment (Mason, 1981). For example, suppose the tool tip cones into contact with a hard surface. Here the environment imposes a natural position constraints which prevents the tool tip from penetrating the hard surface. When the tool is in contact with surface, it no longer makes sense to attempt to control position in the direction orthogonal to surface. However, we can control tool-tip force along direction orthogonal to surface, for example, to maintain contact with the surface. Furthermore, we can simultaneously control the tool-tip position along directions tangent to surface. In this way the tool can be made to slide along the surface.

This is called a compliant move along the hard surface, since the trajectory is made to "comply" with the natural constraints imposed by surface. Recall from the static analysis in $\tau = J^T(q)F^{tool}$ that an external end-of-arm force and movement vector F^{tool} induces a torque τ at the robot joints.

$$\tau = J^T(q)F^{tool} \tag{1}$$

$J(q)$ is $6 * n$ manipulator Jacobian matrix which relates an infinitesimal joint displacement dq to the corresponding infinitesimal tool displacement du.

$$du = J(q)\, dq \tag{2}$$

Supposed we want to design a controller that generates a specified end-of-arm "stiffness", which can be modeled by the following generalized spring equation.

$$F^{tool} = Kdu \quad (3)$$

K might be diagonal with positive diagonal elements.

$$K=diag\{k_1, k_2, \ldots, k_6\} \quad (4)$$

The scalar k_i denotes the stiffness along dimension i. For directions along which position must be controlled, a large value can be assigned to k_i. This has the effect of severely penalizing small displacements in position. For directions

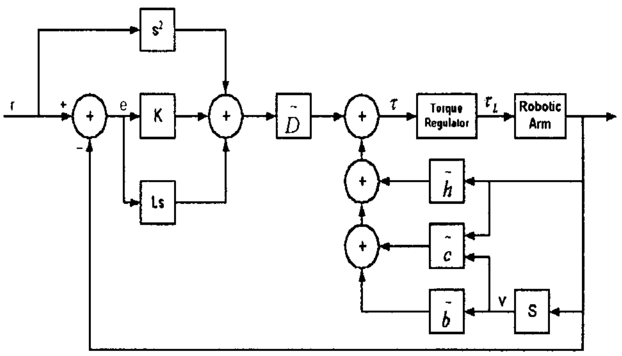

fig 1. Controller of Non-Linear Condition

in which the tool force or moment is controlled only indirectly, because from Eq.(3) we see that it is actually the relationship between force and displacement, the stiffness or mechanical "impedance" of the arm, that is being controlled. Consequently, control techniques which use Eq(3) as their objective are referred to as Impedance Control methods.

Let e denote the difference between the desired tool position and orientation r and the actual position and orientation u. That is, e represents the error, or deflection of the tool from its reference position and orientation.

$$e = r - u \quad (5)$$

If we assume that the error e play the role of du in Eq.(2), then, combining Eqs.(1) and (2), we see that the joint torque required to maintain a desired end-of –arm stiffness is $\tau = J^T(q)Ke$. As a generalization of this formulation, consider the following control law, which also includes damping and the effects of gravity(Asada and slotine, 1986).

$$\tau = J^T(q)[Ke+L\dot{e}]+h(q) \quad (6)$$

Here L is a positive-definite diagonal damping constant matrix, and h(q) represents the load torque due to gravity. Note the similarity between the impedance control law in Eq.(6) and the PD-plus-gravity control law in Eq.(2). The basic difference here is that the error e in Eq.(6) is specified directly in terms of the tool position and orientation: it does not represent joint position error. In addition, the diagonal components of K and l can vary substantially in order to achieve stiffness and damping control in some directions and position control in other directions.

3. Adaptive-Fuzzy Algorithm

It added adaptive fuzzy algorithm in impedance controller for applying robust and flexibility control law about impedance controller's parameter uncertainty and nonlinear terms. When robot contact with environment, robot and environment have each stiffness that is most important factor. Therefore, if we can find robot's stiffness and environment's stiffness exactly this controller is an effective force and position control. Especially, we apply adaptive fuzzy property in One-Link Robot System so we designed adaptive fuzzy impedance control law that can tune target system(controlled motor) stiffness gain value about environment with an arbitrarily stiffness. That is, adaptive fuzzy controller focus that robot doesn't break and move desired position and velocity compliance naturally in environment.

The whole of adaptive fuzzy impedance controller scheme show in fig2. Expert system has Knowledge Base that it is based on impedance control and we are made of rule base with expert system. As we used linguistic value, fuzzy inference engine tune robot stiffness gain value heuristically so robot maintain stability in case of contacting with an arbitrarily stiffness and damping environment.

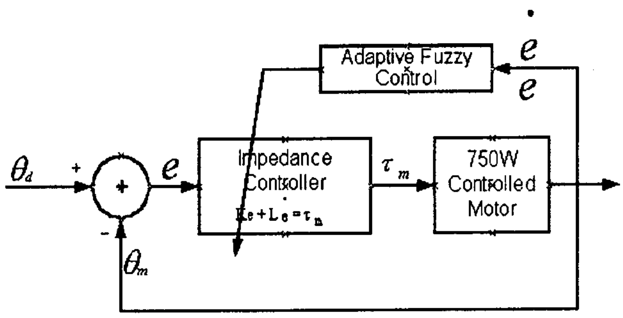

fig 2 Adaptive Fuzzy Controller

For making fuzzy logic, we must select input linguistic value and output linguistic value in One-Link Robot System so we define that position error and change of error express err and derr such as 2 input linguistic value and robot stiffness express K such as output linguistic value.

According to fuzzy linguistic value, err and derr represent.

$$err = \theta_d - \theta_m \quad (7)$$

$$derr = \dot{\theta}_d - \dot{\theta}_m \quad (8)$$

After determining input and output linguistic value, we choose a proper fuzzy number about linguistic value. For example, PB is Positive Big and ZO is ZERO. It is important to determine fuzzy number units so we select fuzzy number units that we get data from one-link system mounted on sensor in experiment and then we has fuzzy partitioning about input and output space with sensor's data because expert can't find every state value in target system.

We constitute rule base with input and output linguistic value, fuzzy number, and knowledge base. It makes rule base about position error and velocity error that is based on input and output linguistic value. As following it is IF-THEN rule ,

Rule = IF err is Ei and
dcrr is Di then is Sti (7)

err : position error linguistic value
derr : velocity error linguistic value
K : robot stiffness
Ei : fuzzy number about error
Di : fuzzy number about change of error(velocity error)
Sti : fuzzy number about robot stiffness

We used Mamdani implication method in One-Link Robot system. We have to know some conditions for setting stiffness gain.

err = desired value - actual value (8)

For example, if and moved, that means robot can't move desired position in case of error, that is, error is plus that means desired value is large than actual value, environment is more rigid than robot. Therefore, robot stiffness choose more large value so robot can move desired position and desired velocity in spite of contacting with environment. However, we can't select absolute robot stiffness value largely because it happened to break stability when robot contact with environment. We consider velocity about robot's moving direction. We see that derr is plus that means the slope is increasing direction so velocity tend to revolute fast.

The result value from Inference engine is still fuzzy value so it deals with defuzzification. We select robot stiffness gain with a good response.

4. System Configuration

As illustrated in fig3, system consists of 750w/400w AC Servo Motor and Torque Sensor.
We can suppose that 750w AC Servo Motor is controlled robot and 400w AC Servo Motor is environment. Torque Sensor is measured reaction force from environment. Transmission Dynamics(coupling) is connected between AC Servo motor and Torque Sensor shaft.

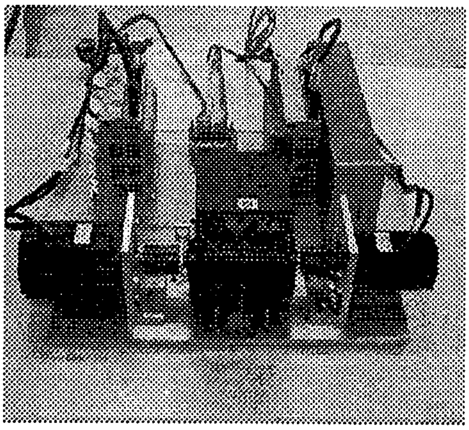

fig 3 System Configuration

We apply Adaptive Fuzzy Impedance controller for controlling One-Link Robot System. According to fig3), we define parameters using this system

Mm : controlled motor inertia
Menv : environment Inertia
Kt : coupling stiffness
Bt : coupling damping

5. Result and Discussion

We used embedded DSP(Digital Signal Processor) board that is calculated so fast operation for controlling One-Link Robot System.

control system sets up that embedded DSP chip (TM S320c4x family) on Dakar F5 carrier board in PCI slot and Imola ISA Quad IP Carrier Board in ISA slot. Imola ISA Quad IP Carrier Board can insert 4 modules in slots. IP-Quadrature exist is Timer/Counter function in slot1 and slot2, D/A Converter exist in slot3, A/D Conver -ter exist in slot4.

Each modules character is that IP-Quadrature has 24bit resolution and four Timer/Counter , D/A Converter has 13bit resolution and 8 channel. A/D Converter has 12bit resolution and 8 channel.

Each modules inserted in slot on Imola ISA Quad IP Carrier Board and the data transmits through IP-Bus. However, we can't use ISA Bus and we used DSP-Link3 data Bus. The data change in Windows NT through PCI Bus. Hardware system connected One-link Robot system, as follows DA converter's two channels allocate for operating AC servo motor and , AD converter's one channel allocate for measuring output data from Torque Sensor. IP-Quadrature allocate that Timer/Counter channel connected encoder signal for measure motor's changing position.

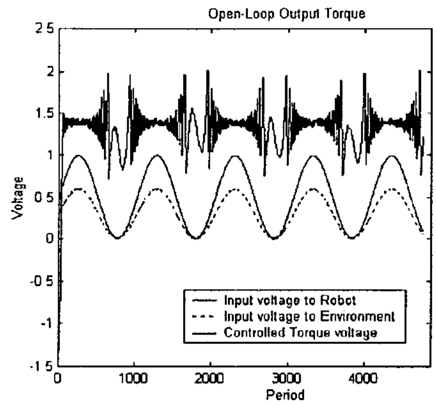

fig 4 Result

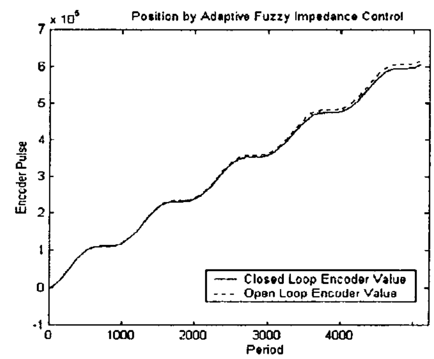

fig 5 Result2

In fig2, it is that the change of output about input signal measure in One-Link Robot system and added adaptive fuzzy algorithm that can control stiffness. We can get the results in experiment.
When robot operate in Open-Loop, fig4 is the result of torque and position. When impedance controller added adaptive fuzzy controller, fig5 is the result of torque and position.

6. Conclusion

while it move also environment sinusoidal velocity, in case of robot that desired input is also sinusoidal function contact with environment, we apply adaptive fuzzy algorithm in One-Link robot system. We can get robust and adaptability results about parameter uncertainty than the existing control algorithm and achieved position and force control fastly.

References

[1] Brian B. Mathewson and Wyatt S. Newman "Integration of force Strategies and Natural Admittance Control," In Proceedings of the ASME Mechanical Engineering Congress and Exposition, pages 237-242, Chicago, IL, 1994.

[2] Gregory D. Glosser and Wyatt S. Newman "The Implementation of a Natural Admittance Controller on an Industrial Manipulator," In Proceedings of the IEEE International Conference on Robotics and Automation, pages 1209-1215, San Diego, CA, May 1994 IEEE.

[3] Wyatt S. Newman and Yuandao Zhang "Stable Interaction Control and Coulomb Friction Compensation Using Natural Admittance Control ," Journal of Robotic systems, 11(1), 1994.

[4] N. Hogan "Impedance Control: An approach to manipulation : Part III-application ," Journal of Dynamic Systems Measurement, and control, vol. 107,pp.17-24, March 1985.

[5] Wyatt S. Newman and Mark E. Dohring "Augment Impedance Control : An Approach to Compliant Control of Kinematically Redundant Manipulators," In Proceeding of the IEEE International Conference on Robotics and Automation, pages 30-35, Sacramento, CA April, 1991, IEEE

[6] Homayyoun Seraji and Richard Colbaugh "Force Tracking in Impedance Control," The International Journal of Robotics Researeb. Vol. 16, No 1, February 1997,pp.97-117.

[7] Miomir K. Vukbratovic and Aleksandar G.Rodic, Yury Ekalo "Impedance Control as a particular Case of the Unified Approach to the Control of Robots Interacting with a Dynamic Known Environment," Journal of Intelligent and Robotics Systems 18: 191-204, 1997.

[8] Ciro Natale and Bruno Siliano Lugi Villani "Spatial Impedance Control of Redundat Manipulators," Proceedings of the 1999 IEEE International Conference on Robotics and Automation Detroit, Michigan. May 1999.

[9] Chien-Chern Cheah and Danwei Wang," Learning Impedance Control for Robotic Manipulators," IEEE Transactions On Robotics and Automation, Vol. 14, No. 3, June 1998.

[10] Seul Jung and T. C. Hsia, "Neural Network Impedance Force Control of Robot Manipulator," IEEE Transactions On Industrial Electronics, Vol, 45, No. 3, June 1998.

[11] Dong Sun and Yunhui Liu ," Modeling and Impedance Control of a two-Maniplator System handling a Flexible Beam," Transactions of the ASME Vol. 119, pgae 736-742. December 1997.