The Eighteenth International Symposium on Artificial Life and Robotics 2013 (AROB 18th '13),
Daejeon Convention Center, Daejeon, Korea, January 30-February 1, 2013

Hybrid control with adaptive and state feedback control for Robot Hand

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Abstract: In this research, we aimed to get an optimum control performance for any kinds of system with the combination of adaptive and state feedback control which are one of modern control theory. Here we used "Gifuhand" which is a hand type robot of 5 fingers as an experimental device. It is optimum experimental device for the purpose of this research to develop the control method which does not spoil controllability under any condition. Because it is the structure imitating human's hand and it is possible to be applied in various scenes. The results of performance such as robustness and accuracy are satisfiable.

Keywords: robot hand, adaptive control, state feedback control, hybrid

1 INTRODUCTION

An adaptive control is expected as next-generation of control method with its very high robustness and easiness for actual use. For example, there is no necessity of parameter tuning in a design phase, and controllability can be maintained to status change of the target in the control process.

However, on the other side it has weak points. Since there exist much computational complexity, the reaction tends to be overdue and the offset is inevitable for system operation.

A state feedback control has the features that are possible to extend to the formula of various optimizations, such as type 1, and type 2 and has very high controllability with adjusting precisely in a design phase except low robustness.

In this research, we propose a hybrid control method which is combined each strong point of above mentioned two control theory, and have high performance such as no offset, saving time and effort of design and maintaining high robustness.

The validity of control and the robustness of adaptation proposed control method were confirmed with the experiments of position control for the robot hand of 5 fingers, 16 DOF and 20 joint and called "Gifuhand" and comparison with conventional method.

2 CONTROL DESIGN

The feature of the proposed control method is to make a good input to make a set variable follow while it replies the optimum gain and an integral gain for every sampling period with a pole assignment method applying the discrete numeric model of the system which is it obtained with iterative least squares technique and the eigenvalue specified beforehand to integral type servo system of discrete state feedback.

Hereinafter, the block diagram of a control system is shown in. Fig.1

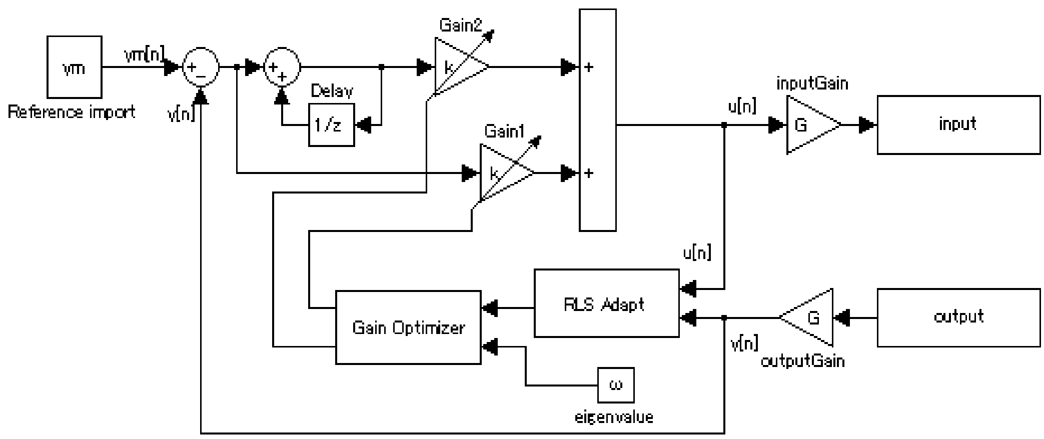

Fig.1 Block diagram of hybrid system

2.1 Discrete-time model

In a basic adaptive control (the RLS method), they perform optimum control with following steps that it calculating the coefficient of the input and output of the difference equation of a system with a least-squares method and substituting them to the equation and a desired value for the future.

To apply this method, we designed control system based on the difference equation using adaptive control in this experiment.

And we designed difference equation as quadratic system considering for the time and effort for a design, accuracy of control, computational complexity, and etc, in the difference equation of the system. Eq.(1)

$$y[n+1] = a_1 y[n] + a_2 y[n-1] + b_1 u[n] + b_2 u[n-1] \quad ..(1)$$

And in order to extend an Eq.(1), a discrete state Eq.(2.1) ~ (2.3) is made to correspond as follows.

$$X[n+1] = AX[n] + Bu[n] \quad ..(2.1)$$

X and y are the followings.

$$X[n] = \begin{bmatrix} x_1[n] \\ x_2[n] \end{bmatrix} \quad ..(2.2)$$

$$\mathrm{y}[\mathrm{n}] = x_2[n] \quad ..(2.3)$$

From Eq.(1) and Eq.(2.1) ~ (2.3), a state variable and A and B can be found uniquely. Each Eq.(3.1) ~ (3.3) can be derived.

$$x_1[n] = a_2 y[n-1] + b_1 u[n-1] \quad ..(3.1)$$

$$x_2[n] = y[n] \quad ..(3.2)$$

$$\mathrm{A} = \begin{bmatrix} 0 & a_1 \\ 1 & a_2 \end{bmatrix}, \mathrm{B} = \begin{bmatrix} b_1 \\ b_0 \end{bmatrix} \quad ..(3.3)$$

The integration clause of a discrete integration type servo system is added into the state equations Eq.(1) and Eq.(2.1) ~ (2.3). The results are Eq.(4.1) ~ (4.2).

$$X[n+1] = AX[n] + Bu[n] \quad ..(4.1)$$

$$A = \begin{bmatrix} 0 & a_1 & 0 \\ 1 & a_2 & 0 \\ 0 & \Delta & 1 \end{bmatrix}, B = \begin{bmatrix} b_1 \\ b_0 \\ 0 \end{bmatrix} \quad ..(4.2)$$

Here X[n] is given from the following equations. And a desired value is given to a state variable in order to converge on it.

$$X[n] = \begin{bmatrix} \hat{x}_1[n] \\ \hat{x}_2[n] \\ W[n] \end{bmatrix} \quad ..(4.3)$$

$$\hat{x}_1[n] = x_1[n] \quad ..(4.4)$$

$$\hat{x}_2[n] = x_2[n] - y_m[n] \quad ..(4.5)$$

$$W[n] = W[n-1] + \Delta(y[n] - y_m[n]) \quad ..(4.6)$$

Here Δ is a sampling period. Eq.(4.6) integrates with the difference of the present output and a target output for every sampling period, and, finally suppress offset

2.2 Control systems

Eq.(5) is given to Eq.(4.1) ~ (4.6) as an input. With a pole placement method and eigenvalue ω, the value of k is calculated, respectively. Eq.(6.1) ~ (6.3).

$$u[n] = -[k_1 \quad k_2 \quad k_3]X[n] \quad ..(5)$$

$$k_1 = \frac{b_0 b_1 (a_2 - a_1 + \Omega_1) - b_0^2(\Omega_2 - a_2) + b_1^2(\Omega_3 + a_1 + 1)}{-b_0 b_1^2 (1 + a_1) + b_1 b_0^2 (a_2 - a_1) + a_2 b_0^3 - b_1^3} \quad ..(6.1)$$

$$k_2 = \frac{-b_1 k_1 + a_1 + 1 + \Omega_3}{b_0} \quad ..(6.2)$$

$$k_3 = \frac{\Omega_2 - a_2 + b_1 k_2 - (a_1 b_1 - a_2 b_0) k_1}{b_1} \quad ..(6.3)$$

Here each Ω is given from Eq.(7.1) ~ (7.3).

$$\Omega_1 = \omega_0\omega_1 + \omega_1\omega_2 + \omega_2\omega_0 \quad ..(7.1)$$

$$\Omega_2 = \omega_0\omega_1\omega_2 \quad ..(7.2)$$

$$\Omega_3 = \omega_0 + \omega_1 + \omega_2 \quad ..(7.3)$$

Since it is a discrete system, the system is stabilized while all eigenvalues are between -1 and 1. However, in this study, all ω are set to 0, in order to save the time and effort of a control design.

2.3 Identification

In calculating a_1, a_2, b_0 and b_1, a iterative least squares mean method (the RLS method) is used. θ[n] and φ [n] are defined as follows.

$$\theta^T[n] = [a_2 \quad a_1 \quad b_1 \quad b_0] \quad ..(8.1)$$

$$\varphi^T[n] = [y[n-1] \quad y[n-2] \quad u[n-1] \quad u[n-2]] \quad ..(8.2)$$

And the value of θ is presumed with iterative least squares mean technique. At every sampling period, this calculation is repeated and each value is derived.

The algorithm is as follows.

$$\theta[n] = \theta[n-1] + \frac{P[n-1]\varphi[n]}{1 + \varphi^T[n]P[n-1]\varphi[n]}\varepsilon[n] \quad ..(9.1)$$

$$\varepsilon[n] = y[n] - \varphi^T[n]\theta[n-1] \quad ..(9.2)$$

$$P[n] = P[n-1] - \frac{P[n-1]\varphi[n]\varphi^T[n]P[n-1]}{1 + \varphi^T[n]P[n-1]\varphi[n]} \quad ..(9.3)$$

$$\theta^T[0] = [1 \quad 1 \quad 1 \quad 1] \quad ..(9.4)$$

$$P[0] = I \quad ..(9.5)$$

3 EXPERIMENTAL SYSTEM

The Gifuhand consists of a thumb and four fingers. The thumb and a finger are modularized for every joint, and unitized for every finger, respectively. The thumb has 4 joint and 4 DOF and other fingers have 4 joint and 3 DOF. It has a total of 20 joint 16 DOF for single hand. This is almost equal to man's DOF of hand, and can imitate a motion of man's hand. In addition, as for an each finger, the 4^{th} joint is connected to the 3^{rd}joint with a parallel link mechanism.

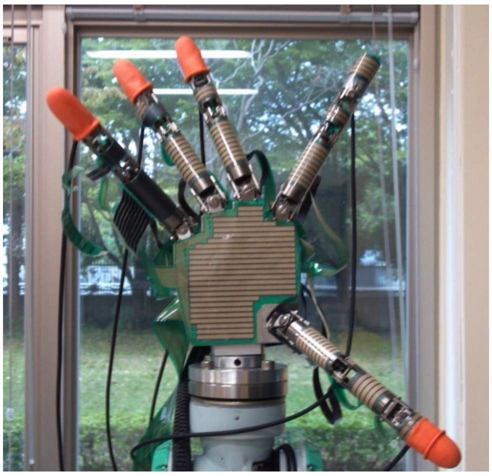

Fig.2 Photo of robot hand

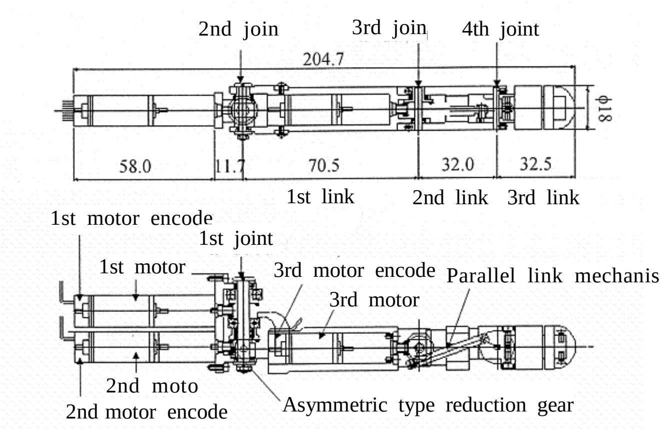

Fig.3 Finger mechanism & size

Fig.2 is the photo of the hand and Fig.3 is the mechanism of the little finger of the experimental device.

Moreover, in this experiment, in order to move a robot hand, a visual C ++ is used for programing and a D/A board, an A/D board, an encoder counter board, and 16-channel power amplifier are used as interface.

The specification of the third joint of the finger used in this experiment is introduced in Table 1.

Table 1 Specifications of robot hand

Speed reduction	148.48:1
Encoder resolution	3.79×10^{-2}[deg]
Max torque	0.20[Nm]
Frequency characteristic	7.0[Hz]
Rating output	1.2[W]
Idling speed	17700[Rpm]
Starting current	673[mA]
Rotor moment-of-inertia	0.286 gcm^2

4 RESULTS AND EVALUATION

The experiments were done for sampling period is 0.01second. All eigenvalues were set to 0.The joint which was used for the experiment was a root joint of a little finger. We gave order to this joint to move 60 deg within 1 sec to the direction of grasping. In every experiment, we set the data of control parameter obtained with pre-operation as initial value. (a_1=1, a_2=0.1, b_0=0, b_1=0)

In this experiment we compared following three methods

(1) Conventional adaptive control
(2) Hybrid control which we are proposed
(3) Hybrid control under loading

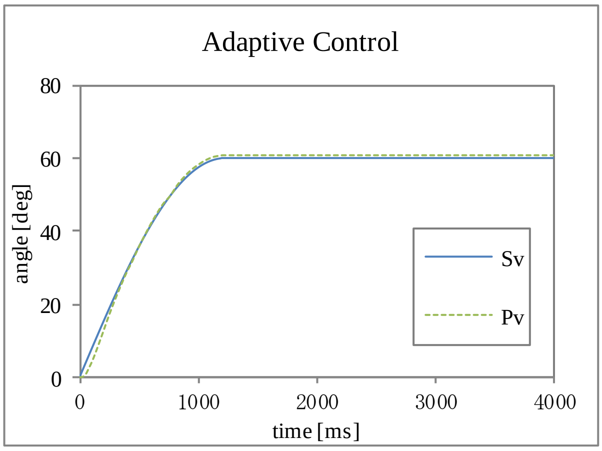

Fig.4 Adaptive control

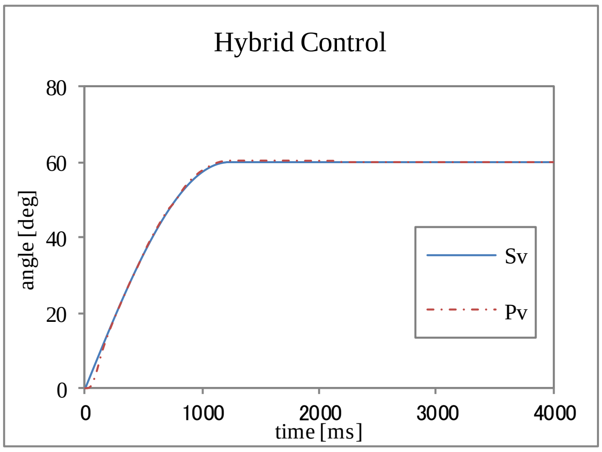

Fig.5 Hybrid control

Fig.4 is the result of conventional adaptive control. Input is a solid line, and output is a dotted line.

Although the outputs follow to the input stably, the small offset error occurs. The detail is shown in Fig.6.

Fig.5 is the result of the Hybrid control. Input is a solid line, and output is a chain line.

Although there is some overshooting of about 2 seconds, it has a high traceability to the change of input. The detail is shown in Fig.6.

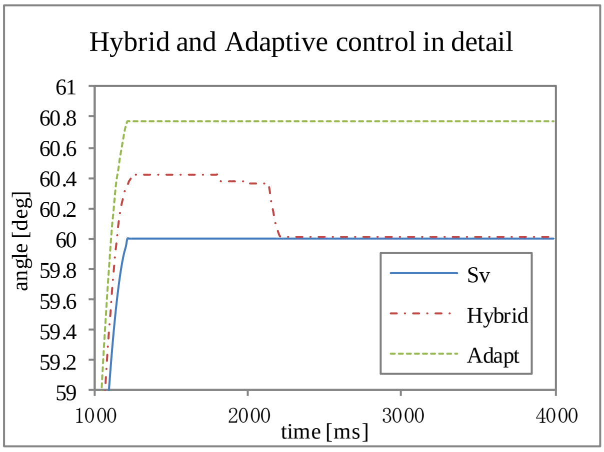

Fig.6 Hybrid and Adaptive in detail

Fig.6 shows the enlarged comparison of the conventional method and a hybrid method. Input is a solid line, Hybrid output is a chain line and conventional output is a dotted line.

This shows the overshoot of Hybrid control is 0.4deg and offset error is very small (0.01deg) and offset error of conventional adaptive control is about 0.8 deg.

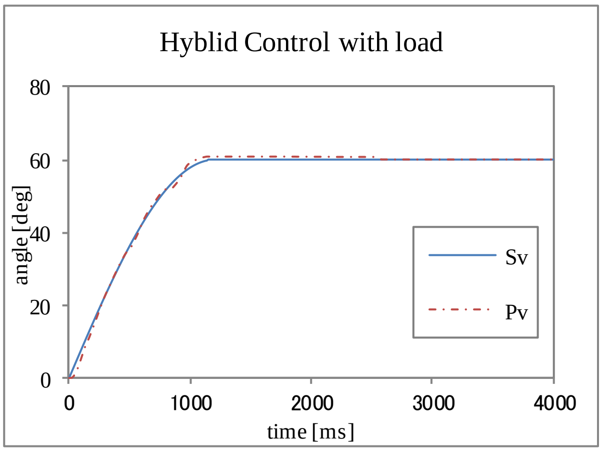

Fig.7 Hybrid control with load

Fig.7 is the result of the Hybrid control under 1kg load. Input is a solid line, and output is a chain line.

Since the load of 1kg is hung to the fingertip, the load moment changes with the motion of finger. It is a kind of hard condition for control. However it shows high robustness that the speed change and shock of motion was not so large to the big change of moment.

5 CONCLUSION

This study showed that hybrid control has high robustness and easiness for adjustment, and higher controllability and accuracy than conventional adaptive control. In particular, the problem of the steady-state error which was a problem until now was solved, and precise control was also attained. Moreover, it can be said that it is very effective in the equipment used for various uses like a robot hand with very high robustness.

However, the shortage of speed which comes from the numerousness of the computational complexity of adaptive control is remained yet. Although this problem is being solved with evolution of a computer, still, it is not enough for high speed control. Solving of this problem will become a future subject.

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