The Hybrid SOF-PID Controller for a MIMO Biped Robot

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Abstract

The application of the hybrid Self-Organizing Fuzzy PID controller to a multi input multi output nonlinear biped robot is studied in this paper. The SOF-PID controller was initially studied by H. B. Kazemian on his papers, [1], [2] and etc. Actually his SOF-PID controller has limits. The supervisory of the SOF-PID controller can adjust only a kinds of parameters. So, In here the hybrid SOF-PID controller are introduced to tune some kinds of parameters and tested on a MIMO biped robot. In experiment the hybrid SOF-PID controller shows better performances than the SOF-PID.

Keywords *: self-organizing fuzzy, biped, pid controller.*

1 Introduction

Over the past few decades many industrial processes have been controlled using PID. Despite of extensive use of PID in conventional control problems, its performance in industrial application is limited. For instance in case of step input problem, it can't show the best performance. For fast response you must suffer bad overshoot property. Even if you succeeded in tuning PID gain to show fine overshoot and ripple you must have some steady state error. In this reason a few replacement algorithm were appeared but It is not necessary to discard an existing controller such as conventional PID, which works well and is already in operation with proper performance even if it is not best. Supervisory controller which can adopt the conventional PID controller is enough and can be good solution.

Kazemian studied the SOF-PID to adjust PID controller which is applied to complex nonlinear system and showed fine performances[1],[2],[3]. He tuned only proportional gains. For other gains of differential gains and Integral gains he used Ziegler-Nichols tuning method because only one kind of parameters, proportional gains, can be tuned using his method. So in here I will suggest the hybrid SOF-PID to adjust all three kinds of PID gains. Though the hybrid SOF-PID can tune all of three PID gains, in experiments actually proportional gains and differential gains are tuned because PD controller is enough to control nonlinear MIMO robot.

Section 2 describes the structure of SOF-PID controller suggested by Kazemian. Section 3 describes the structure of Hybrid SOF-PID controller. Section 4 explains the experimental results of MIMO Biped robot's trajectory following and compares the results with the SOF-PID. Finally Section 5 discusses and concludes the contribution of this work.

2 Basic structure of the SOF-PID controller

The block diagram of Fig.1 shows the basic structure of the SOF-PID controller. This diagram shows the SOF at a supervisory level readjusting the PID gains at an actuator level. An error from the actuator level is fed into the supervisory level to enable the SOF to analyse the process output. There is also an input from the PID controller block to the history of past states block via the PID input section to continuously fuzzify the values of the PID gains. Finally the SOF adjust the PID gains during operation and feeds the results from the output section block into the actuator block. Detail of the SOF block is followed.

- error input section : error and error change are defined as (1), (2) for each.

$$error(e_i) = setpoint(s_i) - system\ output(po_i) \quad (1)$$

$$error\ change(ce_i) = error(e_{i-1}) - error(e_i) \quad (2)$$

  where i is sampling instant. The fuzzification of the error and error change are also done in this block.

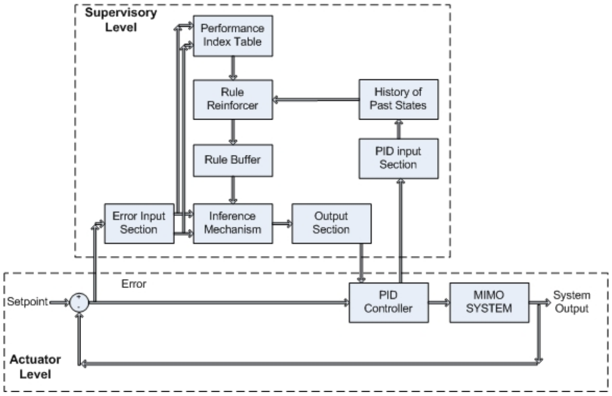


Figure 1: The SOF-PID Controller

- PID input section : The PID gains are fuzzified in this section

- Performance index table : The performance index table is designed as such that if no errors are happened, then no action is taken and the PID gain correction value P is equal to zero. If errors are happened. then PID gain correction P is chosen. Using the equations (1)and (2) a set of thirteen linguistic rules are produced, Table1, and from this a performance index table is obtained.

1. If E is NL and CE is NL or NM or NS then P is ZO.
2. If E is NL and CE is ZO or PS or PM or PL then P is NL.
3. If E is NM and CE is NL or NM or NS then P is ZO.
4. If E is NM and CE is ZO or PS or PM or PL then P is NM.
5. If E is NS and CE is NL or NM or NS then P is ZO.
6. If E is NS and CE is ZO or PS or PM or PL then P is NS.
7. If E is ZO and CE is NL or NM or NS or ZO or PS or PM or PL then P is ZO.
8. If E is PS and CE is NB or NM or NS or ZO then P is PS.
9. If E is PS and CE is PS or PM or PL then P is ZO.
10. If E is PM and CE is NB or NM or NS or ZO then P is PM.
11. If E is PM and CE is PS or PM or PL then P is ZO.
12. If E is PL and CE is NB or NM or NS or ZO then P is PL.
13. If E is PL and CE is PS or PM or PL then P is ZO.

Table 1: Linguistic rules of The SOF-PIDC

NL : -3 or -2.5, NM : -2 or -1.5, NS : -1 or -0.5
ZO : 0, PS : 0.5 or 1, PM : 1.5 or 2, PL : 2.5 or 3

- History of past states : A storage for the fuzzfied values of PID gains. These past states could be retrieved on the basis of first-in and first-out.

- Rule reinforcer : This block update the existing rules and to create new ones. If the PID gain correction P is zero from the performance index table, then no rule modification are taken. If P is not zero, then the rule modification is required for sampling instant i the following equations.

$$K_{Pl}(reinforcer) = K_{Pl-n[i]} + P \tag{3}$$

  where i is the sampling instant, n represents number of samples before the present sample, and l is number of links or robot parameters. $K_{Pl-n[i]}$ is the fuzzified proportional PID gain from the history of past states block.

- rule base : The rule base contains all the appropriate PID gains to be used in the supervisory controller block. The rules are the exact control rule strategy which have been obtained from the learning section of the master controller.

- Inference mechanism : From this block output is produced by combining the e_i, ce_i and the rules from rule base block. Implication function and defuzzification take place in here.

- output section : The output section provides a non fuzzy input signal to be fed into the PID controller. In here the fuzzy signal is dequantised and descaled.

$$K_{P(after-apps)} = K_{P(before-apps)} + U_{Pi} \times K_1 \tag{4}$$
$$K_{D(after-apps)} = K_{D(before-apps)} + U_{Di} \times K_2 \tag{5}$$
$$K_{I(after-apps)} = K_{I(before-apps)} + U_{Ii} \times K_3 \tag{6}$$

  where K_P, K_I, K_D represent the PID gains. The left is prior to changes by the supervisory level and the right is after the change taken place. K_1, K_2, K_3 are the descaled coefficients. U_{Pi}, U_{Di}, U_{Ii} are the output from supervisory controller block.

3 The structure of the hybrid SOF-PID controller

Basic structure of the hybrid SOF-PID controller is same as the SOF-PID controller except the hybrid structure to provide another PID gains, differential gains. In the previous work only proportional gains are provided by the SOF and U_{Di}, U_{Ii} is directly valued by Ziegler-Nichols tuning method : $U_{Di} = 2U_{Pi}/To, U_{Ii} = U_{Pi} \times To/8$, where To is the oscillation period. In the hybrid SOF-PID controller U_{Di} are also provided by the hybrid SOF with relation to U_{Pi}. I aimed to control a MIMO biped robot system and the PD controller is enough to control a biped robot. In this reason integral parameters aren't considered.

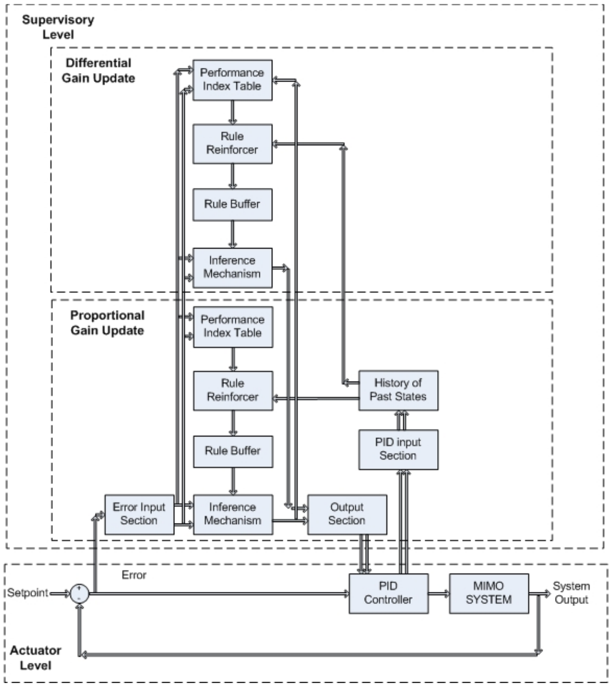


Figure 2: The Hybrid SOF-PID Controller

The detailed block diagram is shown in Fig2. The differential gain update part is for differential parameters of PID control. The different with proportional gain update part is that U_{Pi} is used to readjust U_{Di}. Linguistic rule is shown, Table2. The proposed controller aims to be used on on-line but the hybrid SOF-PID controller needs more computing power than the SOF-PID of previous works. In experiments sampling time is set to more longer than the SOF-PID to reduce computing time.

4 Experiment

A five linked biped robot simulator are used to test The hybrid SOF-PID cotroller and SOF-PID controller. Robot kinematics are used to control robot. Robot joint values are described like Fig3.

α : torso angle
$\Delta\beta = \beta_R - \beta_(L)$: difference of the thigh angles
$\gamma_(L)$: left leg knee angle
$\gamma_(R)$: right leg knee angle

For four joint values, errors are compared between the SOF-PID controller and the hybrid SOF-PID controller in Fig.4,5,6 and 7. It shows that roughly the hybrid SOF-PID controller is better than the SOF-PID controller.

1. If E is NL and CE is NL or NM or NS and Upi is NL or NM or NS then D is ZO.
2. If E is NL and CE is NL or NM or NS and Upi is ZO or PS or PM or PL then D is ZO.
3. If E is NL and CE is ZO or PS or PM or PL and Upi is NL or NM or NS then D is NL.
4. If E is NL and CE is ZO or PS or PM or PL and Upi is ZO or PS or PM or PL then D is NL.
5. If E is NM and CE is NL or NM or NS and Upi is NL or NM or NS then D is ZO.
6. If E is NM and CE is NL or NM or NS and Upi is ZO or PS or PM or PL then D is ZO.
7. If E is NM and CE is ZO or PS or PM or PL and Upi is NL or NM or NS then D is NM.
8. If E is NM and CE is ZO or PS or PM or PL and Upi is ZO or PS or PM or PL then D is NM.
9. If E is NS and CE is NL or NM or NS and Upi is NL or NM or NS then D is ZO.
10. If E is NS and CE is NL or NM or NS and Upi is ZO or PS or PM or PL then D is ZO.
11. If E is NS and CE is ZO or PS or PM or PL and Upi is NL or NM or NS then D is NS.
12. If E is NS and CE is ZO or PS or PM or PL and Upi is ZO or PS or PM or PL then D is NS.
13. If E is ZO and CE is NL or NM or NS or ZO or PS or PM or PL and Upi is NL or NM or NS or ZO or PS or PM or PL then D is ZO.
14. If E is PS and CE is NB or NM or NS or ZO and Upi is NL or NM or NS then D is PS.
15. If E is PS and CE is NB or NM or NS or ZO and Upi is ZO or PS or PM or PL then D is PS.
16. If E is PS and CE is PS or PM or PL and Upi is NL or NM or NS then D is ZO.
17. If E is PS and CE is PS or PM or PL and Upi is ZO or PS or PM or PL then D is ZO.
18. If E is PM and CE is NB or NM or NS or ZO and Upi is NL or NM or NS then D is PM.
19. If E is PM and CE is NB or NM or NS or ZO and Upi is ZO or PS or PM or PL then D is PM.
20. If E is PM and CE is PS or PM or PL and Upi is NL or NM or NS then D is ZO.
21. If E is PM and CE is PS or PM or PL and Upi is ZO or PS or PM or PL then D is ZO.
22. If E is PL and CE is NB or NM or NS or ZO and Upi is NL or NM or NS then D is PL.
23. If E is PL and CE is NB or NM or NS or ZO and Upi is ZO or PS or PM or PL then D is PL.
24. If E is PL and CE is PS or PM or PL and Upi is NL or NM or NS then D is ZO.
25. If E is PL and CE is PS or PM or PL and Upi is ZO or PS or PM or PL then D is ZO.

NL, NM, NS, ZO, PS, PM, PL : same as value in Table 1.

Table 2: Linguistic rules of The Hybrid SOF-PIDC

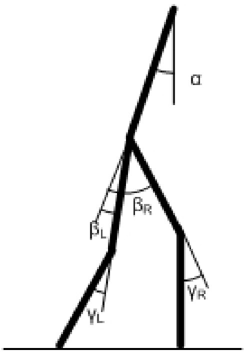
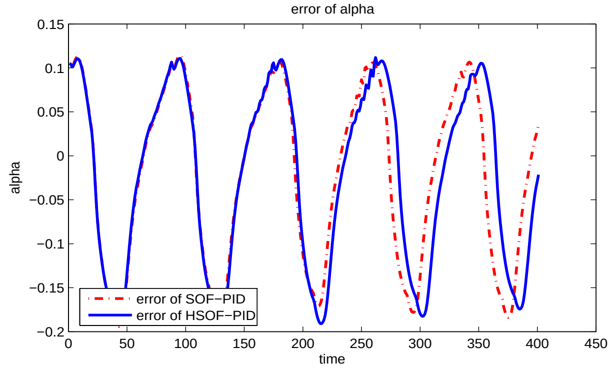
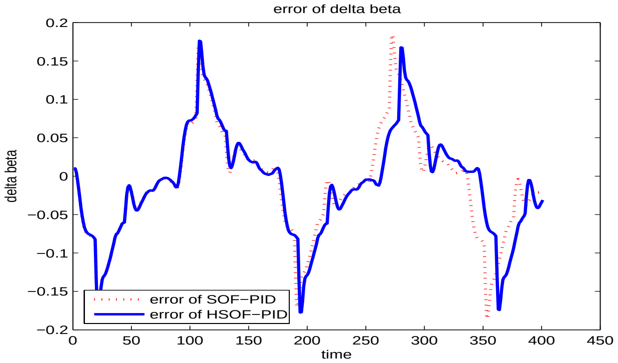
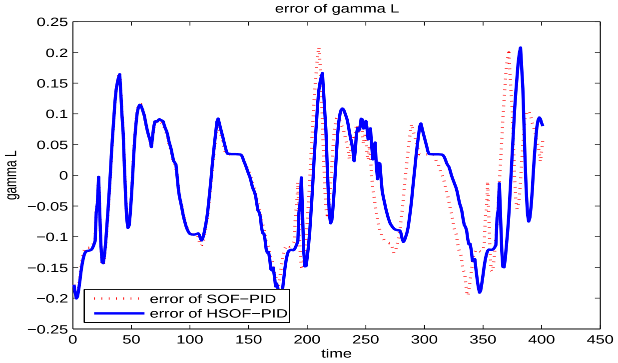


Figure 3: A MIMO Biped Robot







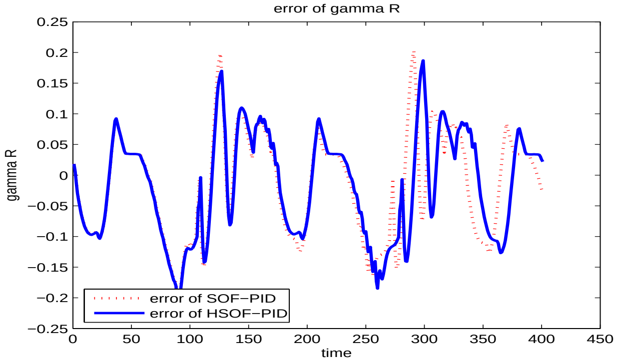


Figure 4: Error of α

Figure 5: Error of $\Delta\beta$

Figure 6: Error of left γ

Figure 7: Error of right γ

5 Conclusion

Both of the hybrid SOF-PID and the SOF-PID controller are tested on a MIMO biped robot simulator. In experiment the hybrid SOF-PID controller shows more smaller error than the SOF-PID as operating time goes. In effect to adjust conventional PID controller the hybrid SOF-PID can be a good solution than the SOF-PID.

The hybrid SOF-PID controller have some drawbacks. First, it need more computing power than the the SOF-PID to apply on on-line control problems. If all three PID gains are tuned computing power will be serious problem. Second it is difficult to construct performance index table without help of experienced human.

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