SELF-TUNING FUZZY PID CONTROLLER USING ONLINE METHOD IN ESSENTIAL OIL EXTRACTION PROCESS

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ABSTRACT: During the extraction process, the temperature plays the major effect on the quality and output yield. Numerous studies on this domain mention that excessive heat during the extraction process will degrade the quality of oil and produced poor output. Recently, researchers take efforts to fix this problem by develop intelligent control technique in order to regulate the temperature. This study proposed the self-tuning fuzzy PID (STFPID) controller using online method. The STFPID controller will regulate the steam temperature below $100^{O}C$ where very little publication so far discussed on that range. The robustness of STFPID controller was test using load disturbance and set point tracking. The performance effectiveness was evaluated based on rise time, settling time, percent overshoot, and steady stare error. From the simulation result, the STFPID controller shows good performance in both transient and steady state dynamics. The STFPID controller also has the ability to track the set point change and curb the load disturbance.

Keywords: STFPID, online tuning, extraction process, robustness test

INTRODUCTION

The ability of the PID controller in process control is well known due to the simple structure and ease of implementation. However, the PID controller is not suitable for nonlinear process and only performed well for linear system. By considering this factor, many researchers take the alternative to design the self-tuning fuzzy PID controllers (STFPID) [1]. The STFPID's operation is based on control laws and will adjust the fuzzy parameter automatically [2].

The STFPID is the hybrid controller since it is the combination of PID and fuzzy scheme. Previous research shown that this hybrid controller shows excellent performances in many application such as motion control or navigation [3,4]. It's have significant advantages over conventional techniques such as PID control. They are cheaper to develop (with equivalent performance), they cover a wider range of operating conditions (i.e., are more robust), not required to know the accurate mathematical model and not sensitive to the change of the parameters of the controlled object [5]. Recently, many researchers apply the STFPID in their work to overcome the weaknesses of PID controller such as in set point tracking and compensate disturbance [6,7].

Many existing research have done by using STFPID in process control. As an example, the STFPID was designed using pole-assignment method to regulate steam temperature of a steam distillation for essential oil extraction process. In order to meet the desired objective, the controller schemes always calculate the fuzzy parameter based on the information from model. As a result, the STFPID able to regulate the steam temperature by show the good performance for robustness tests. [8]. Other application of STFPID to control the temperature can be found in HVAC system. The results show that the controller able meets the desired requirement [9]. The previous researches in the same domain where using STFPID controller in their application can be found in [10-14].

SELF-TUNING FUZZY PID CONTROLLER FOR HEATING PROCESS

In recent years, there has been an increasing interest on temperature control in heating process. Existing publications reported that there are significant correlation between temperature and quality of the essential oil. Figure 1 shows the hydro-diffusion essential oil extraction system. The hydro-diffusion system was implemented with the purpose to extract the essential oil using steam distillation technique.

Figure 1. The extraction system (hydro-diffusion).

The simulink block diagram for self-tuning controller to control the steam temperature of extraction system as in Figure 2:
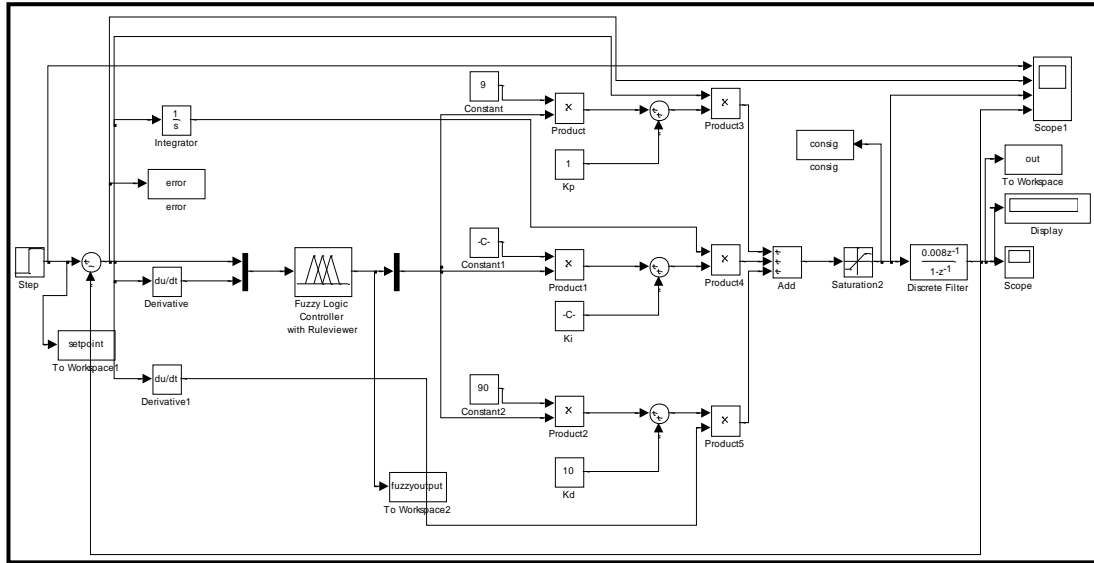
Figure 2. Simulink block diagram of STFPID controller.

The set point was set at 90 $^o C$. Two input variables were defined in terms of linguistics form that is an error, *e(t)* and derivative of error, *de(t)/d(t)*. The value of K_P', K_I' and K_D' are automatically tune by fuzzy controller based on the current value of *e(t)* and *de(t)/d(t)*. The interval for parameters K_P, K_I and K_D supposedly between $[K_{P\ min}, K_{P\ max}]$, $[K_{I\ min}, K_{I\ max}]$ and $[K_{D\ min}, K_{D\ min}]$ forms based on optimum fine tune of PID controller using Ziegler Nichols method as Equations 1 to 3:

$$K_p' = \frac{K_p - K_{p\ min}}{K_{p\ max} - K_{p\ min}} \tag{1}$$

$$K_I' = \frac{K_I - K_{I\ min}}{K_{I\ max} - K_{I\ min}} \tag{2}$$

$$K_D' = \frac{K_D - K_{D\ min}}{K_{D\ max} - K_{D\ min}} \tag{3}$$

Then, the parameters for PID controller as below:

$$K_p = 9K_p' + 1 \tag{4}$$

$$K_I = 0.000009K_I' + 0.000001 \tag{5}$$

$$K_D = 90K_D' + 10 \tag{6}$$

Robustness Test

The robustness of the STFPID was examined by applying the robustness test. The controller is classified as a robust when it able to adapt any changes during the running process. Two robustness tests were implemented which are set point tracking and load disturbance.

For set point changes test, the actual output is expect to follow the set point with minimum error. The performance analysis is based on rise time, settling time, percentage overshoot (% OS) and RMSE. The *r(k)* was set as below:

$$r(k) = \begin{cases} 27\,^oC & ; \quad for\ 0 < k < 2400 \\ 60^oC & ; for\ 2401 < k < 4400 \\ 80^oC & ; for\ 4401 < k < 6400 \\ 90^oC & ; for\ 6401 < k < 8400 \end{cases} \tag{7}$$

For load disturbance test, the system was interrupt during running process at 5000ᵗʰ seconds by dropped the temperature 10 ^oC from set point. The response was evaluate based on the time taken to back to the desired set point.

RESULT AND DISCUSSION

The simulation performances to observe the output using STFPID controller are shown in Figure 3 for 3 membership functions (STFPID-3), Figure 4 for 5 membership functions (STFPID-5) and Figure 5 for 7 membership functions (STFPID-7), respectively. The analysis performances are tabulated in Table 1. The result noticed that all proposed STFPID controller scheme produced a satisfactory responses when the output reach the desired set point with no overshoot. The control signals start to decrease from 5 V to 0 V when the output reached the desired set point. It is shown clearly in figures and tables that the settling time and RMSE value for the STFPID-5 scheme is less than STFPID-3 and STFPID-7. However, the rise time is the same for all STFPID controller schemes.
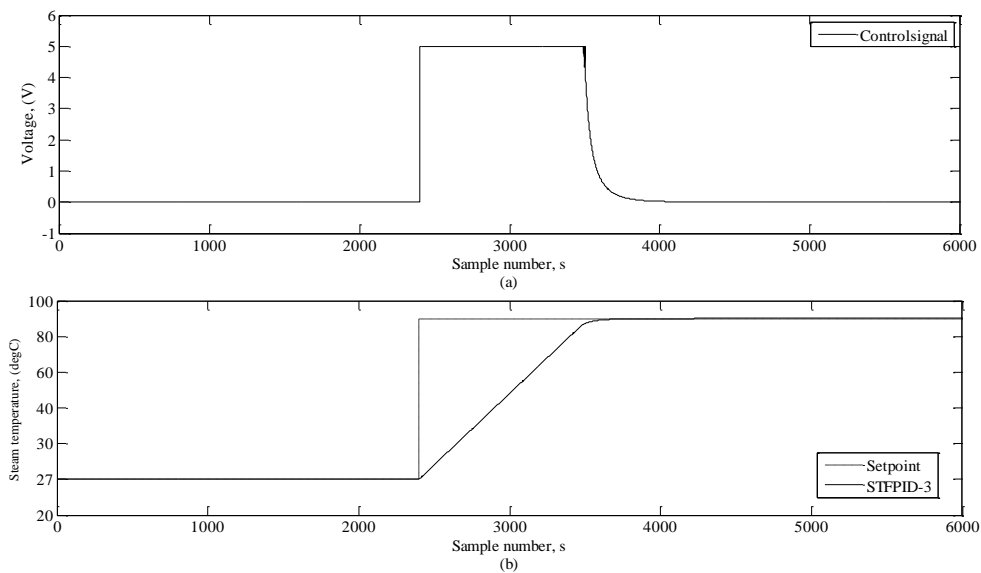
Figure 3. Performance of STFPID-3, (a) control signal, (b) output.
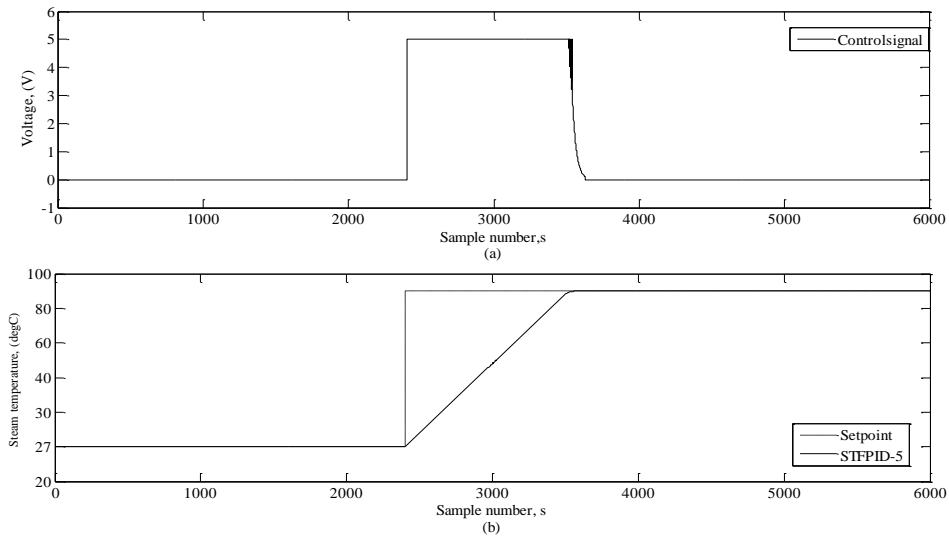
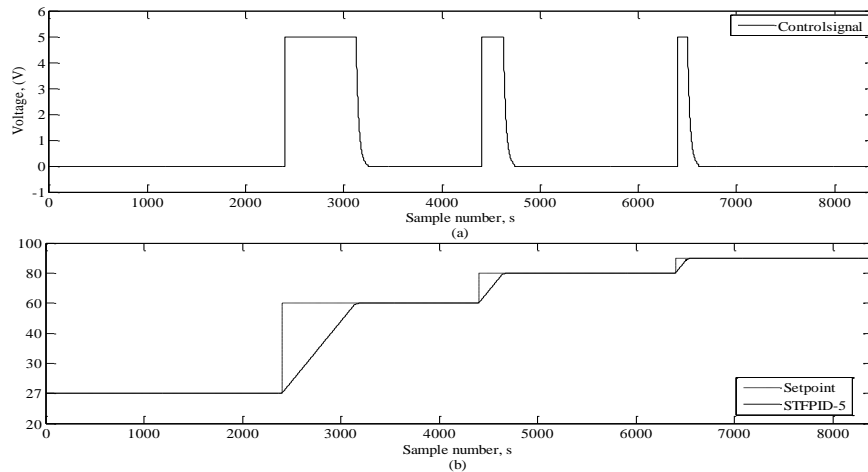**Figure 4. Performance of STFPID-5 (a) control signal, (b) output.**
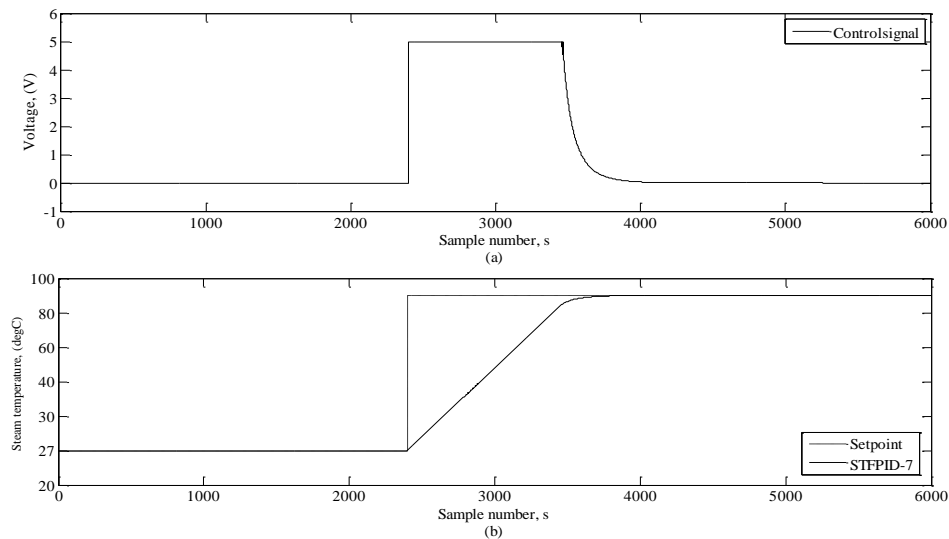
Figure 5. Performance of STFPID-7 (a) control signal, (b) output.

**Table 1. Output for STFPID-3, STFPID-5 and STFPID-7 controller.**

No	Controller	Rise time, (s)	Settling time, (s)	RMSE	% OS
1	STFPID-3	900	3539	0.0575	0
2	STFPID-5	900	3504	0.0141	0
3	STFPID-7	900	3574	0.0529	0

For the robustness test, the STFPID-5 was chosen since it produced the best performance compared with STFPID-3 and STFPID-7. Figure 6 presents the result for simulation performance of STFPID-5 controller on set point changes. From the results, it can be noted that the STFPID-5 controller produces a satisfactory result and robust to face the changes during running process.

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Figure 6. Performance for STFPID-5 on set point tracking, (a) control signal, (b) output.

The result of STFPID-5 on recovering load disturbance is shown in Figure 7. From the result can be noticed that the proposed STFPID-5 scheme take 105 s to go back to the desired set point (90 ^oC) when load disturbance is suddenly added at 5000th samples.
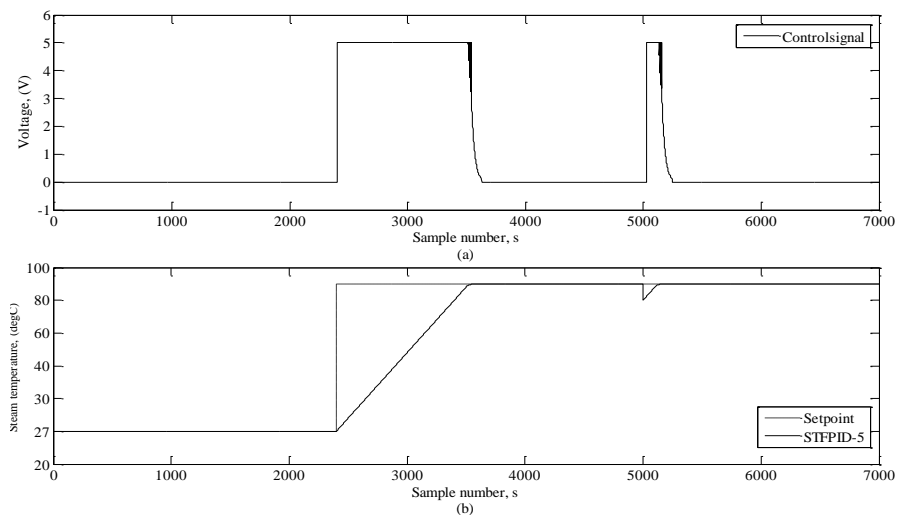
Figure 7. Performance of STFPID-5 on load disturbance, (a) control signal, (b) output.

CONCLUSION

From the results, it can be concluded that the STFPID controller that was apply in regulating the steam temperature for extraction process performs the satisfactory results. It's satisfies the control requirement based in rise time, settling time, %OS and root mean square error. It is also able to adapt any changes during running process.

ACKNOWLEDGMENTS

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