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Real time robustness test evaluation performance for intelligent fuzzy controller in extraction process

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ABSTRACT

This paper presents the real time robustness test using intelligent fuzzy based controller in extraction process of essential oil is discussed in this study. Previous finding shows that the quality of the essential oil is affected by the steam temperature that acts as the control variable in this study. The robustness test is applied to the system during running process to show the system is robust to any operation conditions t make sure the controller is able to give a smooth control output response. The dynamic performance of the system are represented by applying standard performance criteria such as rise time Tr, settling time Ts, overshoot %OS, root mean square error (RMSE) and time on recovering load disturbance. Generally, the objectives in designing the controllers have been achieved because all intelligent fuzzy based controllers capable to regulate the desired set point by acting on the change in the output compared with the set point.

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1. INTRODUCTION

It is very important to consider the robustness test as well as performance in control system design [1-6]. Generally, robustness test is applied to provide controller that can produce a smooth control response and also robust to any changes of the operation conditions during running process [7-10]. Each process is tested on a robustness test which specifies on set point changes and load disturbance. The objective of the set point changes is to force the output of the proposed controller to follow the new set point either by increasing or decreasing the new set point through minimizing the error between the reference and actual signal [7, 9]. Meanwhile, the aim of the load disturbance test is to analyze the capability of the intelligent fuzzy based controller in facing any noise or disturbance [4]. Many types of disturbances can be applied such as the increase of the water flow rate through the distillation column that can affect the process [7], a combination of white noise and sine-wave noise [11] and changes to the composition of raw materials. Numerous works applied the robustness test to check the capability and performance of their proposed controller for the process [3, 12-16].

Controller performance is used to evaluate the controller response by measuring the step response of the controller. The good controller is defined as a controller that could minimize the error between desired target and output in the steady-state manner [17]. The standard performance indexes used in the system's step response are percentage overshoot, rise time, settling time and accumulated error [3-7,18-19]. The percentage overshoot is the percentage of the maximum excess value versus the final value. The rise time is the time for the step response to reach from 0 to its final value. The accumulated error is the summation of the absolute error of the step response at the sampling instants [19]. The settling time is the time taken to attain the nearly constant value of set point [19-21]. This performance index was applied to many applications and it is desirable to optimize a number of different system performances to meet some requirements such as smaller overshoot, minimizing the settling time of the output, fast rise time, smaller steady-state error and the smaller load effect [19].

2. RESEARCH METHODOLOGY

Robustness test for real time performance was done using two intelligent fuzzy based controllers which are hybrid fuzzy PID controller (HFPID) and self-tuning fuzzy PID controller. These two controllers were attached to the extraction process in order to control the steam temperature. Each process is tested on a robustness test which is set point changes and load disturbance. There are three set point tracking set which are at 60 oC, 80 oC and 90 oC. 10 oC of the disturbance is injected on 5000th sample onwards from the set point. The controller's design robustness is measured by the rapidness of the output returns from the desired point. The objective of the disturbance test is to analyze the controller's optimum ability and its performance to recover load disturbance in the least time possible with introduced upset conditions. Generally, the purpose of the robustness test is to analyse the capability of each controller in adapting the disturbance during running process. The controller can be said to be robust if it is able to track the desired set point in all situations even when set point changes and can cause an abrupt disturbance during running process. The details of intelligent fuzzy controller configuration can be found in [3, 23-26]

3. RESULTS AND ANALYSIS

3.1. Set Point Test

The result for intelligent fuzzy based controller using PID, HFPID using 7 membership function and STFPID for 5 membership function is shown in Figure 1. The result shows that all the controllers are able to track the set point changes by producing excellent performance in terms of rise time, settling time and %OS. All controllers are able to meet the desired set point with HFPID-7 and STFPID-5 shows the outperform result as compared with the PID. However, the PID controller provides comparable performance of RMSE value as HFPID-7 and STFPID-5.

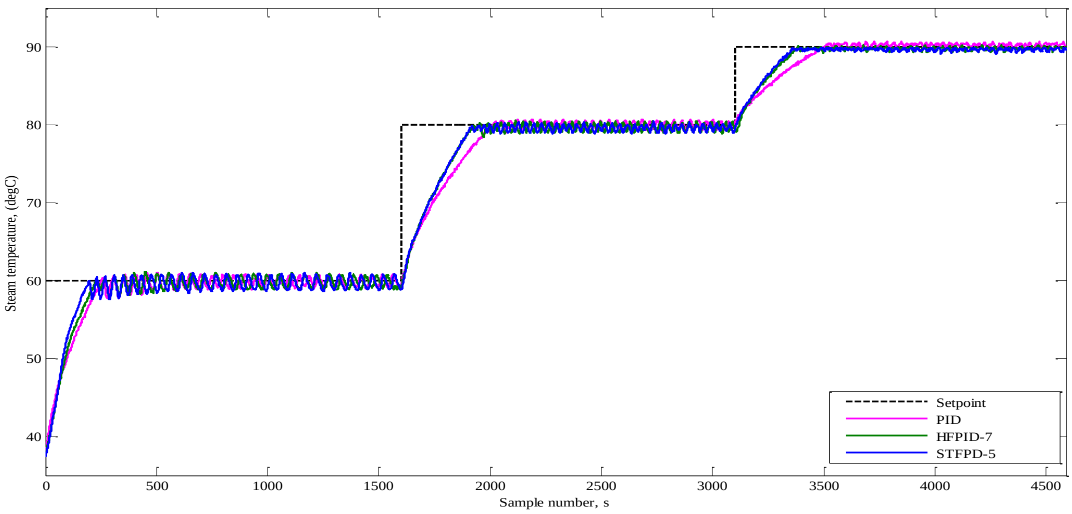

Figure 1. Set point test

The evaluation result for real time set point tracking at 60 oC is tabulated in Table 1. Based on analysis, it shows that at set point 60 oC, the self-tuning fuzzy-5 provides superior result as compared with PID and HFPID-7 controller. The STFPID-5 provides 129 s of rise time, 1581 s of settling time, 0.8354 of %OS and 0.7372 of RMSE. This result shows that STFPID-5 outperformed than others controller by producing the rise time less 62 s, settling time less 13 s, %OS less 0.2754 and RMSE less -0.0243 than PID controller. The HFPID-7 also produced very encouraging results where the rise time less 60 s, settling time less 3 s, %OS less 0.1998 and RMSE less -0.0574 than the PID controller. The STFPID-5 also produced comparable performance of rise time with a HFPID-7 controller. However, the settling time, %OS and RMSE shows that STFPID-5 is better compared with HFPID-7 with settling time less 10 s, %OS less 0.0756 and RMSE less 0.0331 than HFPID-7.

Table 1. Comparison of Real Time Performance of PID, HFPID-7, and STFPID-5 on Set Point Test (Set Point 60 oC)

No	Controller	Rise time, (s)	Settling time, (s)	%OS	RMSE
1	PID	191	1594	1.1108	0.7129
2	HFPID-7	131	1591	0.9110	0.7703
3	STFPID-5	129	1581	0.8354	0.7372
HFPID-7 compared with PID		60 s (1 min)	3 s	0.1998	-0.0574
STFPID-5 compared with PID		62 s (>1 min)	13 s	0.2754	-0.0243
STFPID-5 compared with HFPID-7		2 s	10 s	0.0756	0.0331

Table 2 shows the detail analysis for comparison of PID, HFPID-7, and STFPID-5 controllers to track the set point change (at set point 80 oC). Based on the analysis, it shows that at set point 80 oC, the STFPID-5 provides the best performance compared with other controllers. The STFPID-5 provides 245 s of rise time, 1484 s of settling time, 0.4953 of %OS and 0.5677 of RMSE. The rise time, settling time, %OS and RMSE for PID controller is 328 s, 1495 s, 0.7462 %OS and 0.4087, respectively. This result shows that the rise time, settling time, %OS and RMSE for STFPID-5 is 83 s, 11 s, 0.2509 and -0.1590 less than PID controller. The HFPID-7 provides 247 s of rise time, 1495 s of settling time, 0.5047 of %OS and 0.5566 of RMSE. The difference between STFPID-5 and HFPID-7 is 2 s, 11 s, 0.0094 and -0.0111 for rise time, settling time, %OS and RMSE, respectively. The STFPID-5 was produced comparable performance of rise time and settling time with a HFPID-7 controller. Meanwhile, the PID controller performed the best performance at steady-state by producing the lowest RMSE.

Table 2. Comparison of Real Time Performance of PID, HFPID-7, and STFPID-5 on Set Point Test (Set Point 80 oC)

No	Controller	Rise time, (s)	Settling time, (s)	%OS	RMSE
1	PID	328	1495	0.7462	0.4087
2	HFPID-7	247	1495	0.5047	0.5566
3	STFPID-5	245	1484	0.4953	0.5677
HFPID-7 compared with PID		81 s (>1 min)	-	0.2415	-0.1479
STFPID-5 compared with PID		83 s (>1 min)	11 s	0.2509	-0.1590
STFPID-5 compared with HFPID-7		2 s	11 s	0.0094	-0.0111

Table 3 tabulated the analysis for comparison of real time performance of PID, HFPID-7, and STFPID-5 controller at set point tracking 90 oC. Overall, the result shows that at set point 90 oC, the STFPID-5 provides the outperformed performance compared with PID and HFPID-7 controller. The rise time, settling time, %OS and RMSE for PID controller is 334 s, 1496 s, 0.6723 %OS and 0.3135, respectively. The HFPID-7 provides 216 s of rise time, 1497 s of settling time, 0.3371 of %OS and 0.2851 of RMSE. Meanwhile, the STFPID-5 provides 206 s of rise time, 1478 s of settling time, 0.3249 of %OS and 0.3040 of RMSE. This result shows that the rise time, settling time, %OS and RMSE for STFPID-5 is 128 s, 18 s, 0.3474 and 0.0095 less than PID controller. The difference between STFPID-5 and HFPID-7 is 10 s, 19 s, 0.0122 and -0.0189 for rise time, settling time, %OS and RMSE, respectively.

Table 3. Comparison of Real Time Performance of PID, HFPID-7, and STFPID-5 on Set Point Test (Set Point 90 oC)

No	Controller	Rise time, (s)	Settling time, (s)	%OS	RMSE
1	PID	334	1496	0.6723	0.3135
2	HFPID-7	216	1497	0.3371	0.2851
3	STFPID-5	206	1478	0.3249	0.3040
HFPID-7 compared with PID		118 s (>1 min)	-1 s	0.3352	0.0284
STFPID-5 compared with PID		128 s (>2 min)	18 s	0.3474	0.0095
STFPID-5 compared with HFPID-7		10 s	19 s	0.0122	0.0189

3.2. Load disturbance

Figure 2 shows a comparison performance for disturbance test among 3 different implemented controllers that was attached to the extraction system.

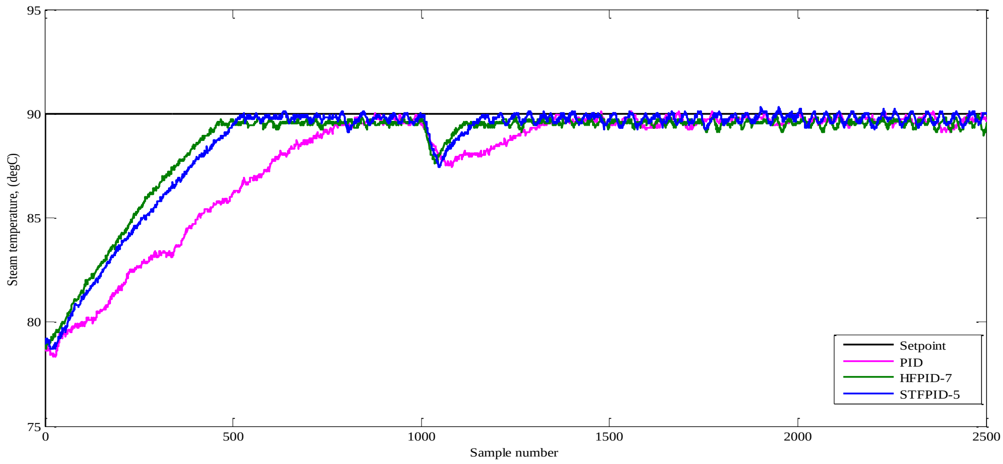

Figure 2. PID, HFPID-7 and STFPID-5 performance on recovering load disturbance

Table 4 summarized the results for real time performance of PID, HFPID-7 and STFPID-5 controllers on recovering load disturbance, whereas Figure 3 shows the comparison of speed which the output returns to the set point for all proposed controllers. From the result in the Table 4, after introducing the disturbance at sample 1000th, steam temperature decreases with Tmin= 87.42 oC, Tmin= 87.50 oC and Tmin= 87.42 oC for proposed PID, HFPID-7 and STFPID-5 controllers, respectively. All controllers shows the capability of correcting the process disturbances and compensating for the errors by capturing back the set point after the system was disturbed during running process. However, these results revealed that the good robustness of the HFPID-7 and STFPID-5 controllers since PID controller took the longest time to recover from the upset caused by a process disturbance with 386 s. The time taken to capture back the set point after introduced disturbance for HFPID-7 controller using 49 rules is five times faster, which is only 74 s as compared with PID controller with 386 s. The recovery process is significantly shortened for HFPID-7 by taking 312 s less than PID controller. Significant improvement can be spotted for HFPID-7 controller because it provides speedy recovery and robust response in comprising an abrupt disturbance during running process. The results also demonstrate that the STFPID-5 offer better performance by greatly improve the recovery process compared with PID controller. The STFPID-5 takes 285 s less than PID controller. On the other hand, the control signals for all proposed controllers display similar patterns. The control signal varies between 0 V to 5 V at a steady-state. However, when subjected to load disturbance at 1000th samples, the control signal maintained at 5 V. The developed controllers pushed the steam temperature to return to the set point as fast as possible.

Table 4. Analysis for Disturbance Test

No	Controller	T_{min}	Recovery time (s)
1	PID	87.42 ^oC	386
2	HFPID-7	87.50 ^oC	74
3	STFPID-5	87.42 ^oC	101
HFPID-7 compared with the PID			-312
HFPID-7 compared with the STFPID-5			-27
STFPID-5 compared with the PID			-285

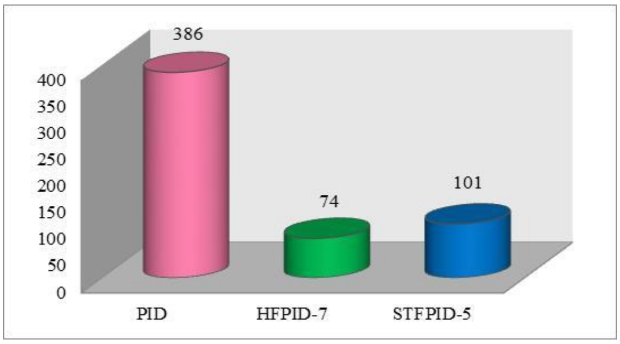

Figure 3. Graphical comparison of recovery time for all proposed controllers

4. CONCLUSION

Generally, the objectives in designing the controllers have been achieved since all the implemented fuzzy based controller manage to regulate the desired steam temperature at desired set point by acting on the change in the output compared with the set point. This study has shown that PID, HFPID-7 and STFPID-5 controller have the ability to curb the disturbance that has been suddenly interrupted during running process.

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