

Supporting Information

Multi-loop Integral Controllability Analysis for Nonlinear Multiple-Input Single-Output Processes

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Results for the Embedded Temperature Control System

- Close-loop Characteristics for Rising Set-point at 40°C (see Figure S1 and Table S1)

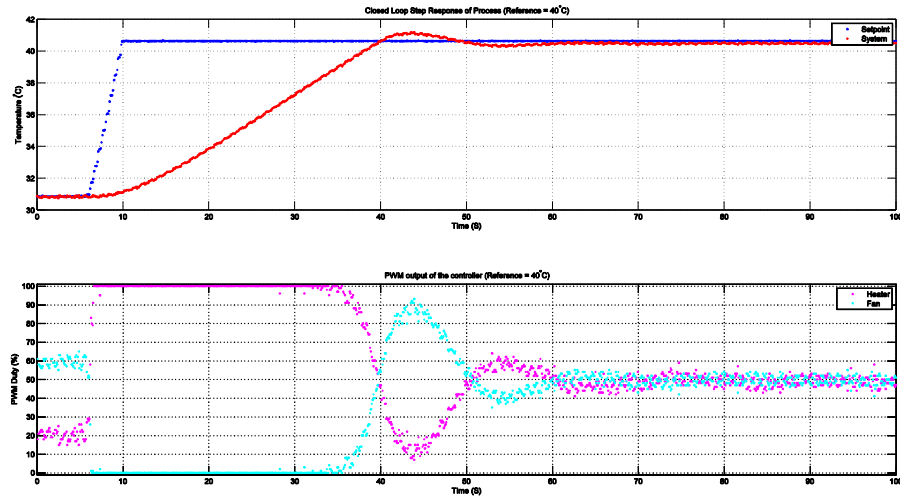


Figure S1. Rising Set-point at 40°C

Property	Value	Unit
Set-point	40.64	°C
Final Value	40.48	°C
Steady State Error	0.16	°C
Max Overshoot	41.17	°C
Settling Time	42.23	second
Delay Time	7.536	second
Rise Time	33.4	second
Response Time	40.936	second

Table S1. Rising Set-point at 40°C

- Close-loop Characteristics for Rising Set-point at 50°C (see Figure S2 and Table S2)

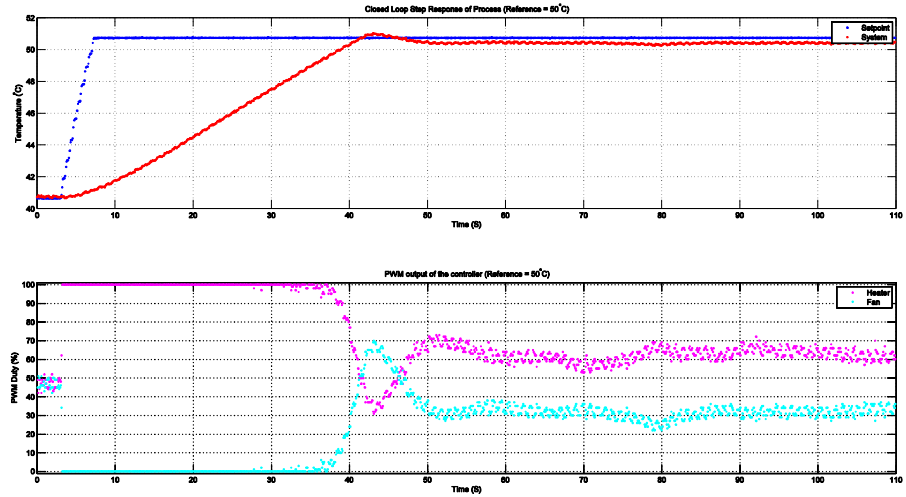


Figure S2. Rising Set-point at 50°C

Property	Value	Unit
Set-point	50.74	°C
Final Value	50.5	°C
Steady State Error	0.24	°C
Max Overshoot	51.02	°C
Settling Time	40.372	second
Delay Time	7.143	second
Rise Time	34.2	second
Response Time	41.343	second

Table S2. Rising Set-point at 50°C

- Close-loop Characteristics for Rising Set-point at 60°C (see Figure S3 and Table S3)

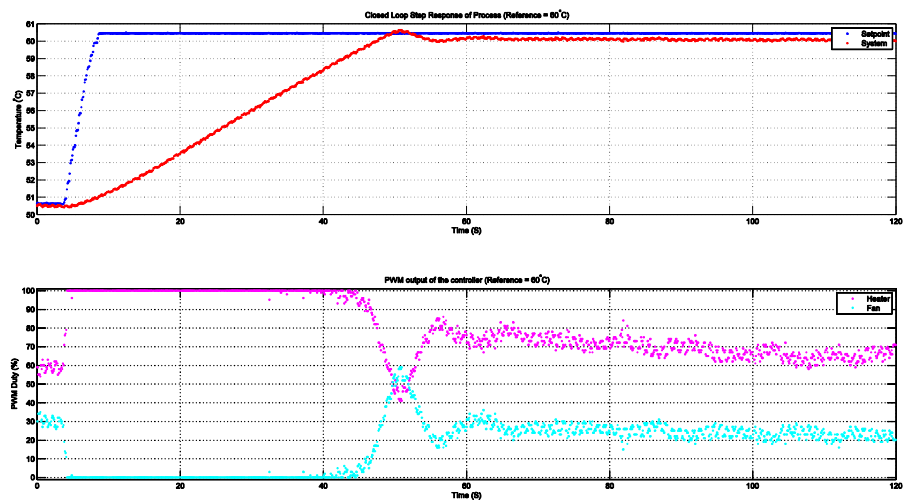


Figure S3. Rising Set-point at 60°C

Property	Value	Unit
Set-point	60.54	°C
Final Value	60.07	°C

Steady State Error	0.38	°C
Max Overshoot	60.64	°C
Settling Time	47.83	second
Delay Time	7.93	second
Rise Time	39.72	second
Response Time	47.57	second

Table S3. Rising Set-point at 60°C

- Close-loop Characteristics for Rising Set-point at 70°C (see Figure S4 and Table S4)

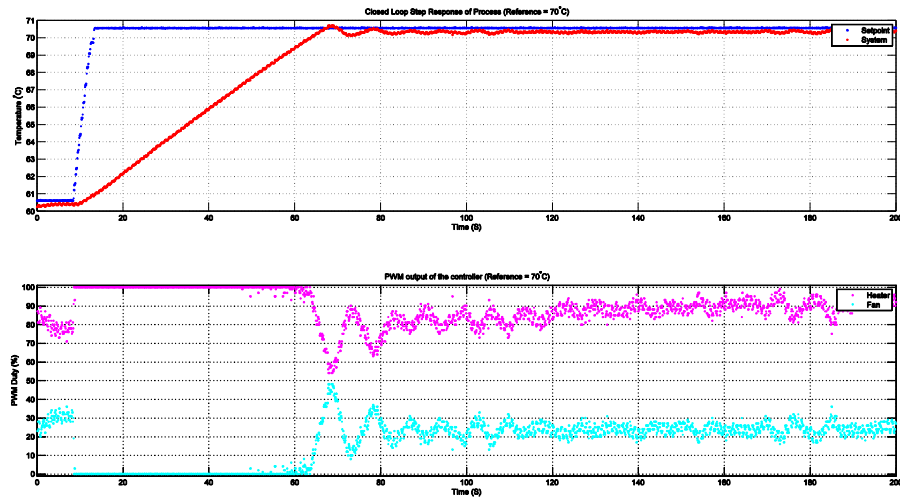


Figure S4. Rising Set-point at 70°C

Property	Value	Unit
Set-point	70.57	°C
Final Value	70.31	°C
Steady State Error	0.26	°C
Max Overshoot	70.72	°C
Settling Time	56.56	second
Delay Time	7.51	second
Rise Time	51.33	second
Response Time	58.84	second

Table S4. Rising Set-point at 70°C

- Close-loop Characteristics for Rising Set-point at 80°C (see Figure S5 and Table S5)

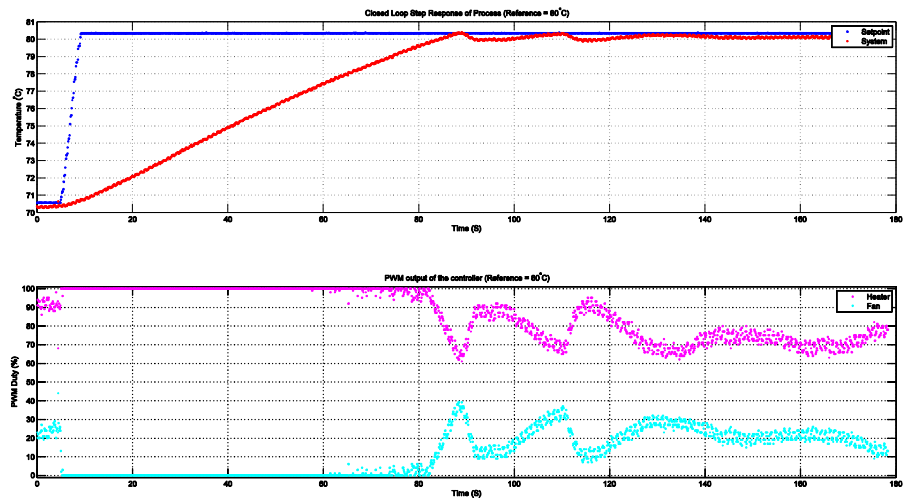


Figure S5. Rising Set-point at 80°C

Property	Value	Unit
Set-point	80.33	°C
Final Value	80.11	°C
Steady State Error	0.22	°C
Max Overshoot	80.4	°C
Settling Time	76.03	second
Delay Time	9.5	second
Rise Time	70.7	second
Response Time	80.2	second

Table S5. Rising Set-point at 80°C

- Close-loop Characteristics for Falling Set-point at 30°C (see Figure S6 and Table S6)

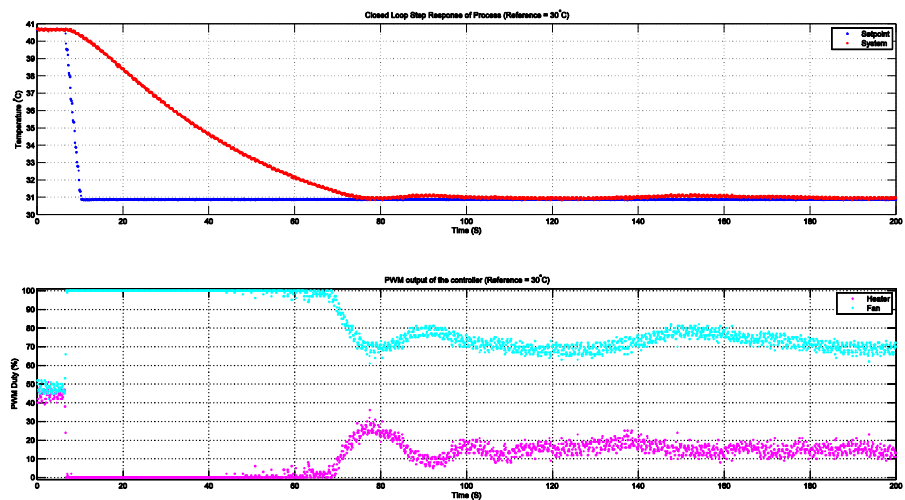


Figure S6. Falling Set-point at 30°C

Property	Value	Unit
Set-point	30.86	°C
Final Value	30.94	°C

Steady State Error	0.08	°C
Max Overshoot	30.83	°C
Settling Time	61.39	second
Delay Time	6.63	second
Rise Time	56.44	second
Response Time	63.07	second

Table S6. Falling Set-point at 30°C

- Close-loop Characteristics for Falling Set-point at 40°C(see Figure S7 and Table S7)

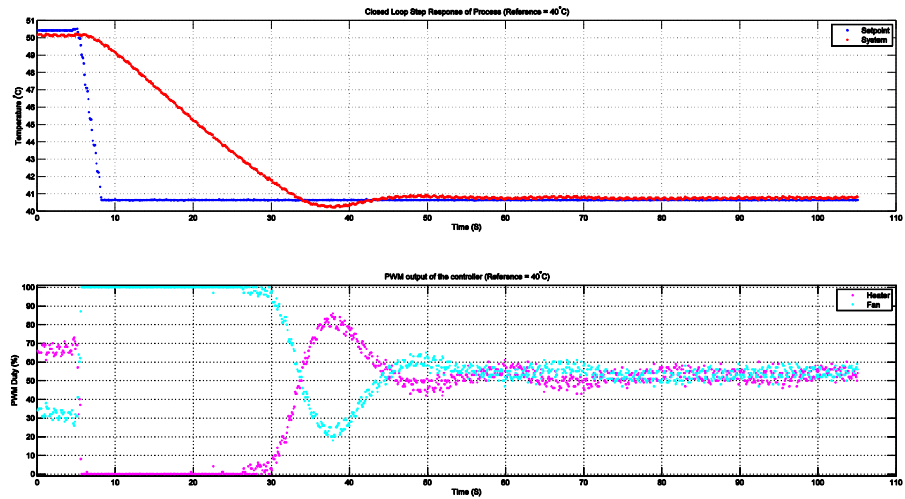


Figure S7.Falling Set-point at 40°C

Property	Value	Unit
Set-point	40.64	°C
Final Value	40.73	°C
Steady State Error	0.09	°C
Max Overshoot	40.21	°C
Settling Time	34	second
Delay Time	5.05	second
Rise Time	24.86	second
Response Time	29.91	second

Table S7. Falling Set-point at 40°C

- Close-loop Characteristics for Falling Set-point at 50°C(see Figure S8 and Table S8)

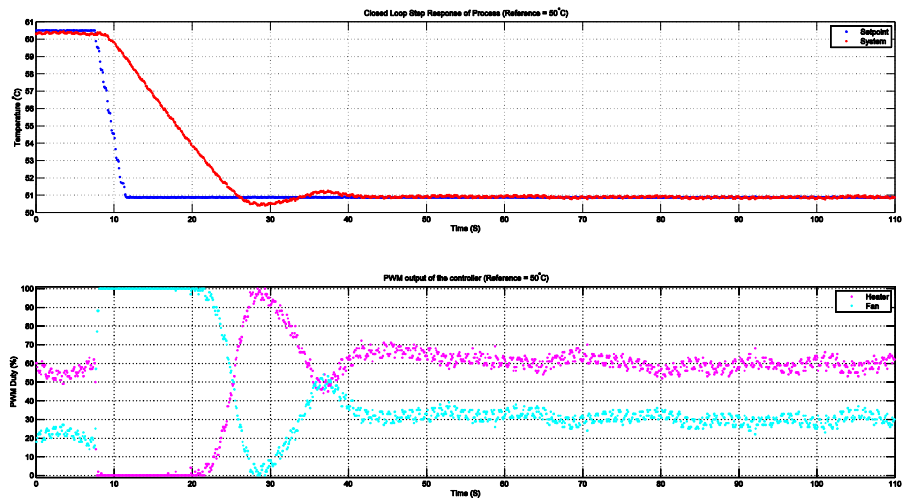


Figure S8.Falling Set-point at 50°C

Property	Value	Unit
Set-point	50.87	°C
Final Value	50.91	°C
Steady State Error	0.04	°C
Max Overshoot	50.41	°C
Settling Time	17.23	second
Delay Time	3.44	second
Rise Time	16.09	second
Response Time	19.53	second

Table S8. Falling Set-point at 50°C

- Close-loop Characteristics for Falling Set-point at 60°C (see Figure S9 and Table S9)

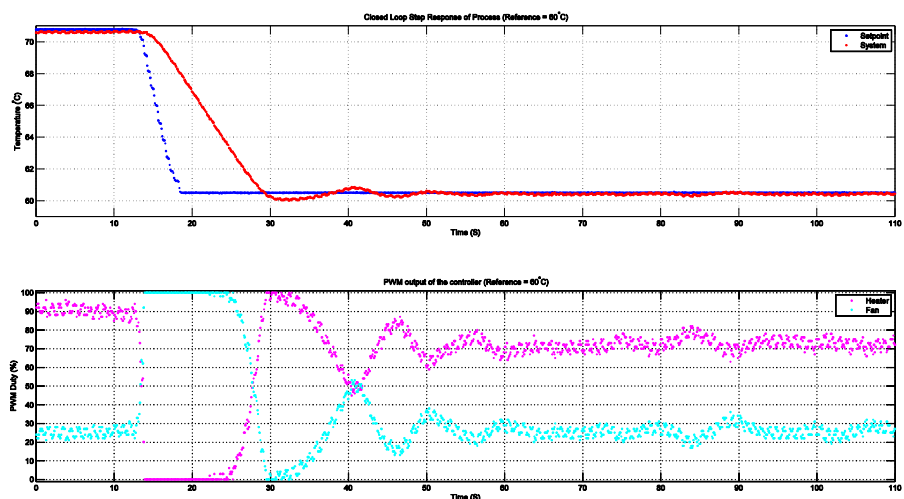


Figure S9.Falling Set-point at 60°C

Property	Value	Unit
Set-point	60.5	°C
Final Value	60.39	°C

Steady State Error	0.11	°C
Max Overshoot	60.01	°C
Settling Time	14.84	second
Delay Time	2.84	second
Rise Time	14.37	second
Response Time	17.21	second

Table S9. Falling Set-point at 60°C

- Close-loop Characteristics for Falling Set-point at 70°C(see Figure S10 and Table S10)

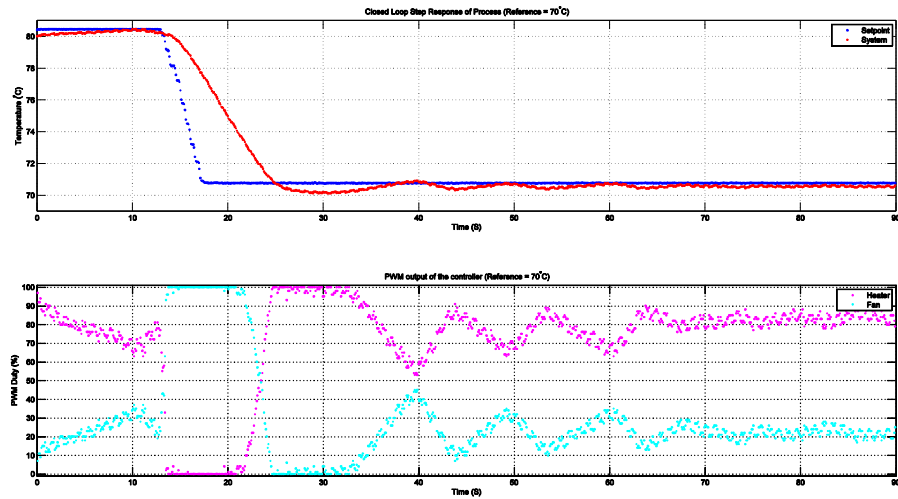


Figure S10.Falling Set-point at 70°C

Property	Value	Unit
Set-point	70.76	°C
Final Value	70.57	°C
Steady State Error	0.19	°C
Max Overshoot	70.12	°C
Settling Time	11.51	second
Delay Time	2.28	second
Rise Time	10.75	second
Response Time	13.03	second

Table S10. Falling Set-point at 70°C

- Heater Controller Rising Step (see Figure S11 and Table S11)

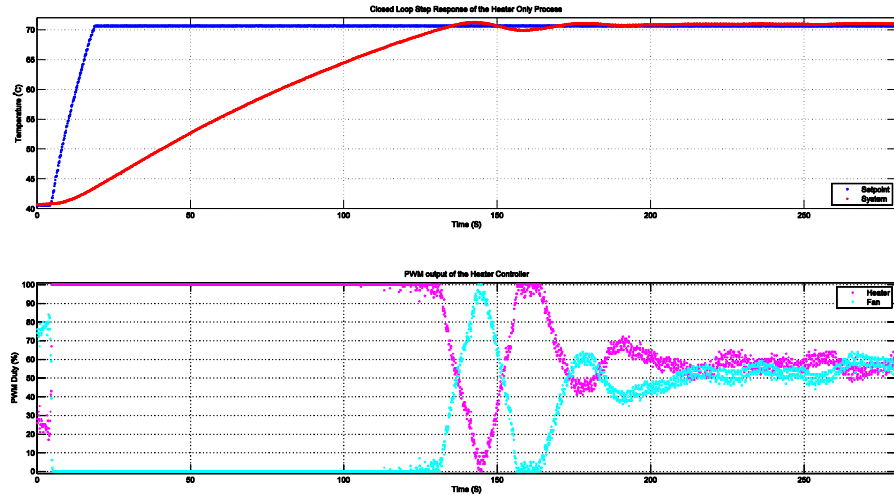


Figure S11.Heater Controller Rising Step

Property	Value	Unit
Set-point	70.65	°C
Final Value	70.81	°C
Steady State Error	0.16	°C
Max Overshoot	71.25	°C
Settling Time	162.7	second
Delay Time	15.68	second
Rise Time	113.6	second
Response Time	129.28	second

Table S11. Heater Controller Rising Step

- Heater Controller Falling Step (see Figure S12 and Table S12)

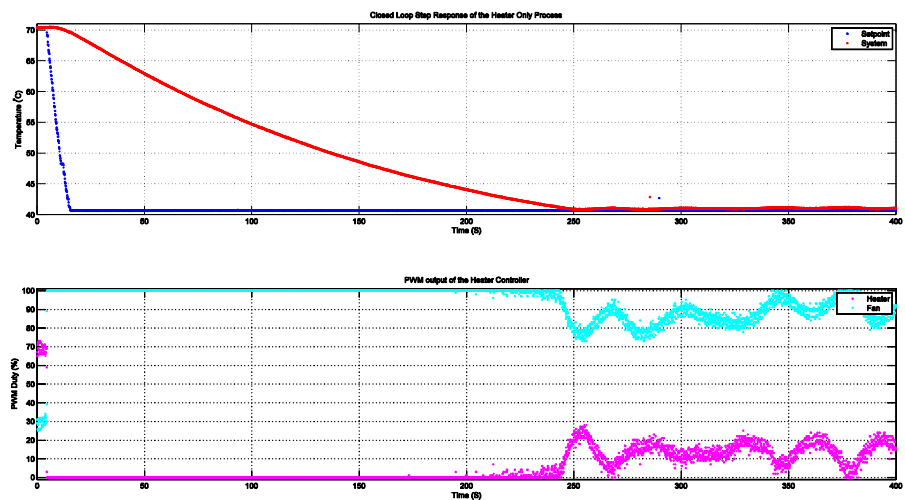


Figure S12.Heater Controller Falling Step

Property	Value	Unit
Set-point	40.65	°C
Final Value	40.87	°C

Steady State Error	0.22	°C
Max Overshoot	40.78	°C
Settling Time	234.65	second
Delay Time	22.47	second
Rise Time	197.6	second
Response Time	219.77	second

Table S12. Heater Controller Falling Step

- Fan Controller Rising Step (see Figure S13 and Table S13)

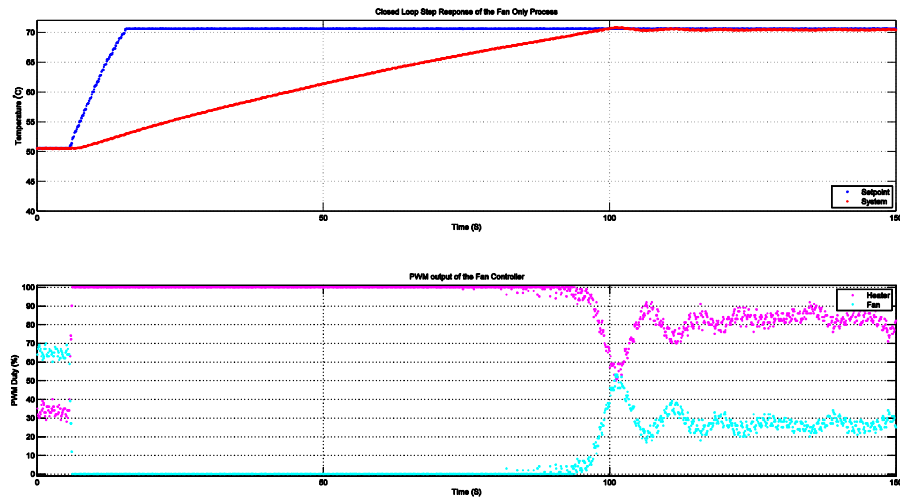


Figure S13.Fan Controller Rising Step

Property	Value	Unit
Set-point	70.62	°C
Final Value	70.43	°C
Steady State Error	0.19	°C
Max Overshoot	70.84	°C
Settling Time	90.38	second
Delay Time	11.88	second
Rise Time	75.93	second
Response Time	87.81	second

Table S13.Fan Controller Rising Step

- Fan Controller Falling Step (see Figure S14 and Table S14)

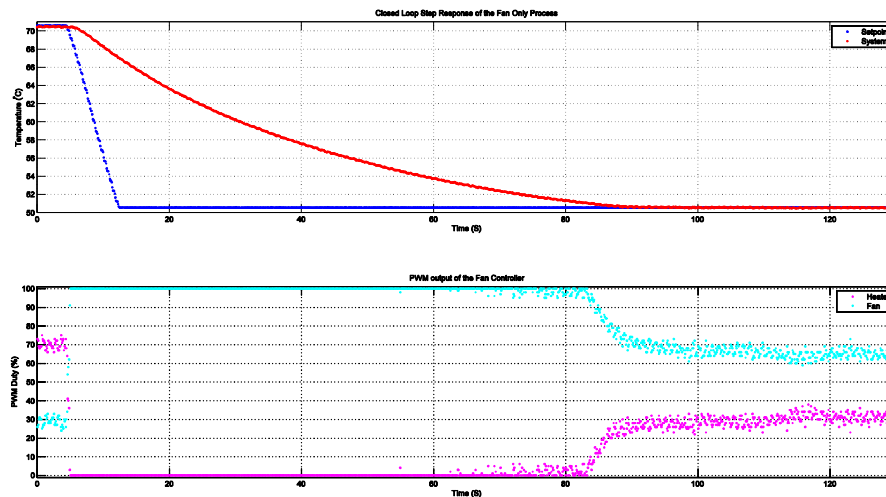


Figure S14.Fan Controller Falling Step

Property	Value	Unit
Set-point	50.57	°C
Final Value	50.52	°C
Steady State Error	0.05	°C
Max Overshoot	50.43	°C
Settling Time	79.45	second
Delay Time	5.3	second
Rise Time	63.78	second
Response Time	69.08	second

Table S14.Fan Controller Falling Step

- Both Controllers Rising Step (see Figure S15 and Table S15)

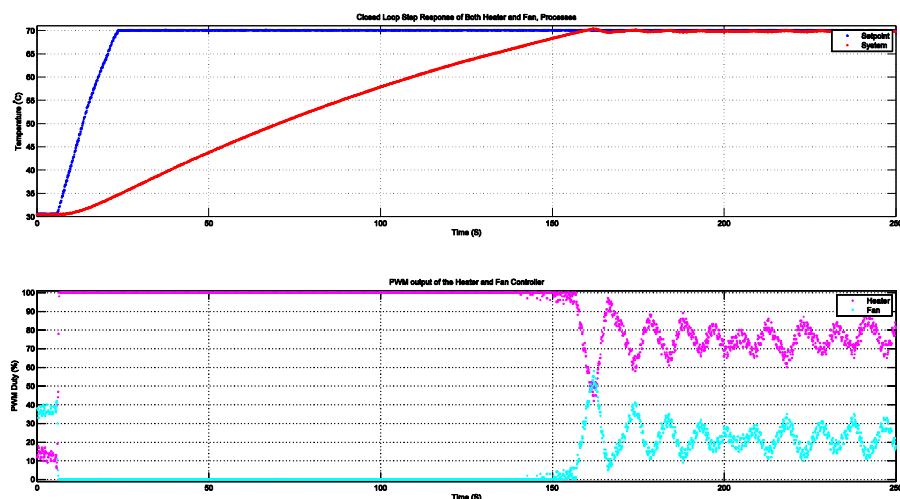


Figure S15. Both Controllers Rising Step

Property	Value	Unit
Set-point	70.07	°C
Final Value	69.72	°C

Steady State Error	0.35	°C
Max Overshoot	70.38	°C
Settling Time	157.3	second
Delay Time	14.2	second
Rise Time	135.9	second
Response Time	150.1	second

Table S15. Both Controllers Rising Step

- Both Controllers Falling Step (see Figure S16 and Table S16)

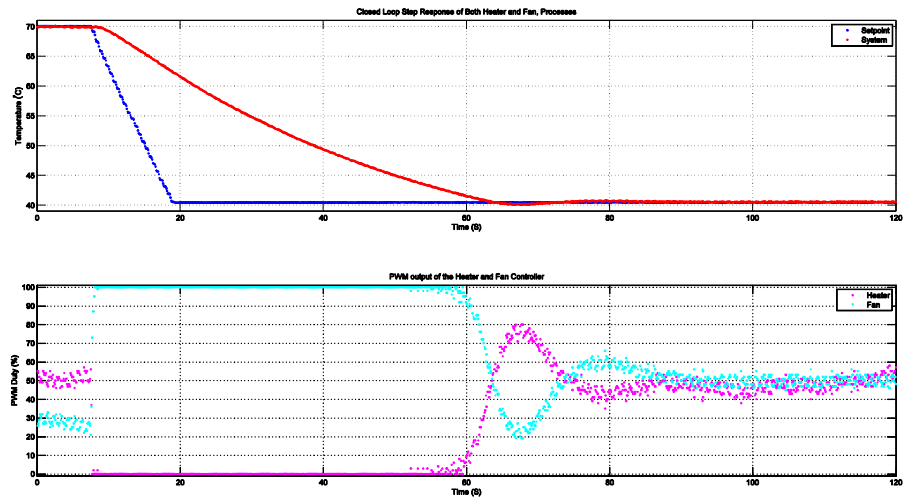


Figure S16. Both Controllers Falling Step

Property	Value	Unit
Set-point	40.45	°C
Final Value	40.53	°C
Steady State Error	0.08	°C
Max Overshoot	40.07	°C
Settling Time	54.24	second
Delay Time	5.7	second
Rise Time	46.42	second
Response Time	53.12	second

Table S16. Both Controllers Falling Step