Design of Temporal Controller for Small Oven Process Using STM32F103RE

T. Suksri[1], V. Boonpranchoo[2], V. Kongratana[3], V. Tipsuwanporn[4] and A. Numsomran[5]

***Abstract*— This paper presents the design temporal controller for small oven process using STM32F103RE, MCU ARM 32-bits microcontroller. The research concerns to design embedded controller for temperature control applications that require both precision control and affordable costs. The proposed system is based on form of On-Off control devices together with Temporal Logic algorithm that can provide high precision and accuracy, furthermore; decrease the damage to contactors and valves by slowing down the control cycling. The experiment operated by Real-Time Workshop Embedded Coder run on RapidSTM32 Block Set of the STM32 FIO boards. RapidSTM32 converted Simulink Matlab program to a working embedded system and collected the process data to Matlab workspace. The experimental results have been shown that the design of Temporal Logic embedded controller can achieve the performance specification requirement in temperature control.**

***Index Terms*— Temporal Logic, Embedded Controller, Small Oven Process**

I. Introduction

IN thermal control processes (boilers, furnace, hard disk drives testing ovens, etc.) widely use On-Off method to control temperature [1] for non-precise control system because it is the simplest and least expensive form of control available. For the practical problems associated with On- Off control in the industrial processes such the rapidly-cycling control has damaged contactors and valves, so several others control methods have been used for solving the problem such as PID control which provides more accuracy and stable control; however, in some cases, PID control is unsuitable because the cost of PID analog control system is high; therefore, there are the gap for some applications that require both precision control and affordable costs.

The aim of this paper is to propose the design of temporal logic embedded controller for small oven process. The embedded control system which is based on form of On-Off control devices can provide high precision and accuracy, furthermore; decrease the damage to contactors and valves by slowing down the control cycling. The performance of control system was tested with Fio board, STM32F103RE ARM 32-bits microcontroller and Simulink program. The time domain characteristics are compared with On-Off Stateflow and PID control method.

[1] Department of Instrumentation Engineering, Faculty of Engineering, Pathumwan Institute of Technology, Bangkok 10330, Thailand
[2,3,4,5] Department of Instrumentation and Control Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand, Tel:66-81925-0356, E-mail: knarjin@kmil.ac.th

The results have been shown that Temporal Logic controller can achieve the performance specification requirement in temperature control. Its control cycling is slower than simple On-Off controller, hence the damage to actuator equipment is able to decrease, and thus Temporal Logic algorithm will be another solution for embedded control system that require both control performance and affordable costs.

The remainder of the paper is organized as follows. In Section 2, we introduce methodology of Temporal Logic Control. Section 3 describes an implementation of temperature controller. Section 4 explains experiment and results. Finally, The conclusions are given in section 5.

II. Temporal Logic

Temporal logic controls execution of a Stateflow chart in terms of time. In state actions and transitions, two types of temporal logic can be used: event-based and absolute-time. Event-based temporal logic keeps track of recurring events, and absolute-time temporal logic defines time periods based on the simulation time of your chart. To operate on these recurring events or simulation time, built-in functions called temporal logic operators have been used.

A. after Temporal Logic Operator

The after operator checks whether an event occurs after a specified time.

Syntax : after(n, sec)

where n is any positive number or expression and sec is a keyword that denotes the simulation time elapsed since activation of the associated state.

B. before Temporal Logic Operator

The before operator checks whether an event occurs before a specified time.

Syntax : before(n, sec)

where n is any positive number or expression and sec is a keyword that denotes the simulation time elapsed since activation of the associated state.

C. Graphical Function

A Stateflow graphical function is a function defined graphically by a flow diagram. Graphical functions reside in a Stateflow chart along with the diagrams that invoke them, and they can accept arguments and return results. Graphical functions can be invoked in transition and state actions

Stateflow chart in Fig.1 is used for control the air temperature followed step input in a small oven plant. The Stateflow controller chart contains 3 exclusive (OR) states (Heater.On, Heater.Off and Off.Flash). It has 4 graphical

ISBN: 978-988-19251-7-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

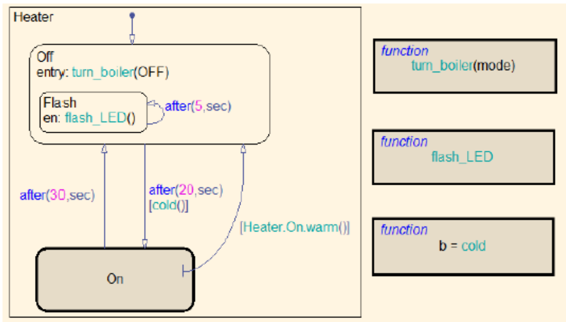

Fig. 1. Temporal Logic Stateflow diagram

functions (Function On, Function turn_boiler, Function flash_LED and Function cold). Stateflow controller chart provides conditions on the transitions between Heater.Off and Heater.On, and between Heater.On and Heater.Off, based on the time of supplying voltage to heater.

III. Implementation of Temperature Controller

A. Hardware

Temperature control for small oven process shown in Fig.2 consists of Fio, STM32F103RE ARM 32-bits embedded microcontroller board, 1-5V to 4-20mA signal converter, 650W solid state small oven plant, type K thermocouple and $0-200^{\circ}C$ to 1-5V TC transmitter.

B. Software

As showing in fig. 3, the experimental programs generated by Real-Time Workshop Embedded Coder run on RapidSTM32 Block Set of the STM32 FIO boards. RapidSTM32 converted Simulink Matlab program to a working embedded system and collected the process data to Matlab workspace. The Simulink diagram of On-Off stateflow control, Temporal Logic and PID control has been shown in Fig.4, 7 and Fig.10 respectively.

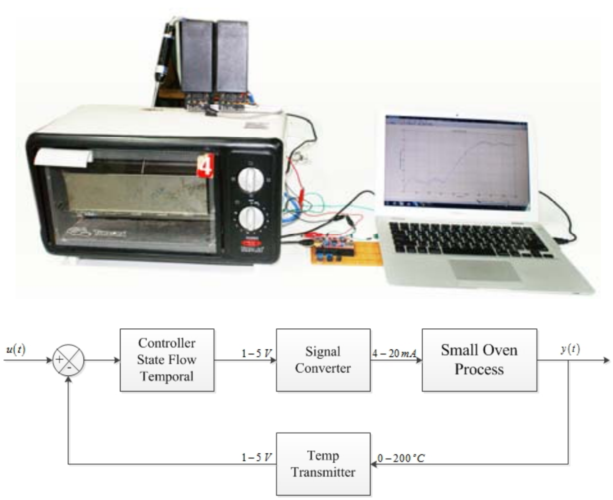

Fig. 2. Temperature control for small oven process

.

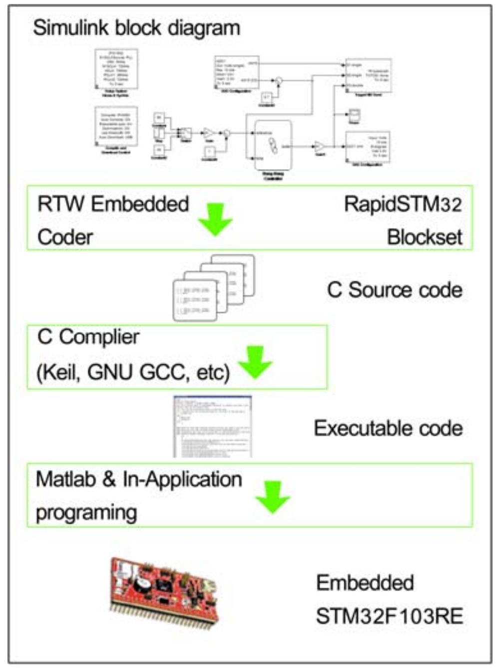

Fig. 3. Procedure of embedded code generating

IV. Experiment and Results

Using experimental equipment of small oven control system in Fig.2, our proposed approach has been tested. From the initial condition $y(0) = 20.0^{\circ}C$, the target is to follow a control reference for $40.0^{\circ}C$ and $60.0^{\circ}C$ at $t = 0$ sec and $t = 1000$ sec with sampling time $T_s = 1$ *msec*. Testing for the tolerance to the influence from disturbance was done at $t = 2000$ sec.

A. On-Off Stateflow

In first case, we did the experiment for On-Off Stateflow control as showing in block diagram in Fig.4. The performances of small oven process using On-Off Stateflow control are shown in Fig.5 ~ 6.

B. Temporal Logic Stateflow

In second case, we did the experiment for Temporal Logic Stateflow control as showing in block diagram in Fig.7. The performances of small oven process using Temporal Logic Stateflow control are shown in Fig.8 ~ 9.

C. PID Control

In Final case, we did the experiment for PID control as showing in block diagram in Fig.10. The performances of small oven process using PID control are shown in Fig.11 ~ 12.

The comparison of the proposed approach which is made by determining % overshoot and settling time of output response over entire experimental period is shown in Fig.13 and Table 1.

ISBN: 978-988-19251-7-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

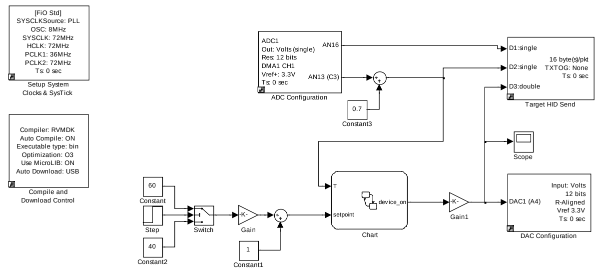

Fig. 4. On-Off Stateflow Simulink Diagram

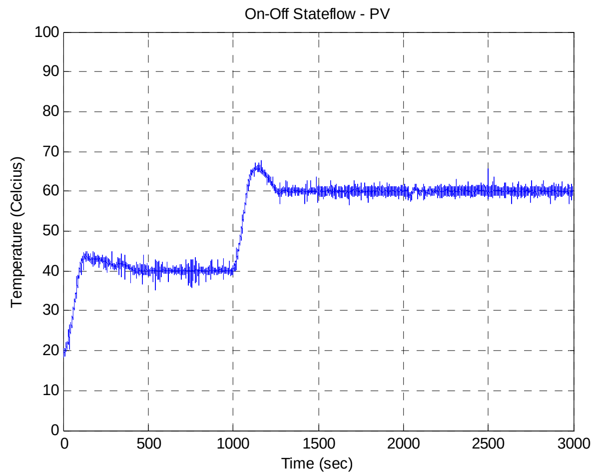

Fig. 5. Step Response of On-Off Stateflow Control

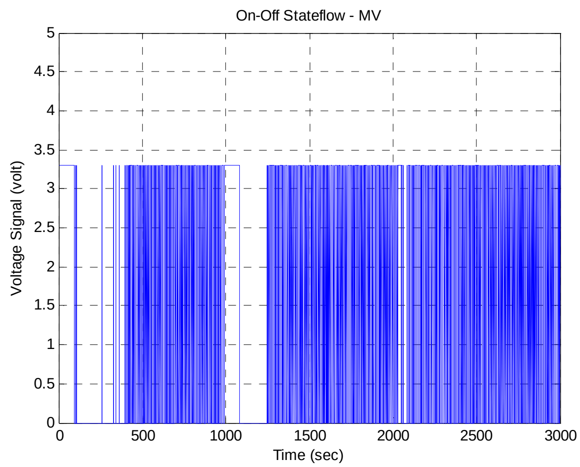

Fig. 6. Control Signal of On-Off Stateflow Control

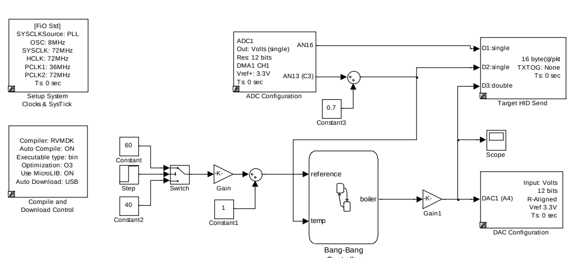

Fig. 7. Temporal Stateflow Simulink Diagram

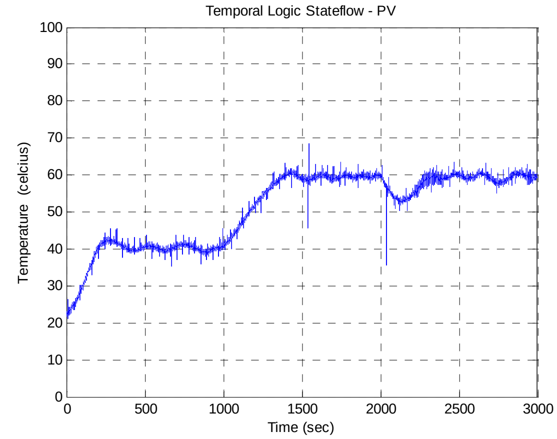

Fig. 8. Step Response of Temporal Stateflow Control

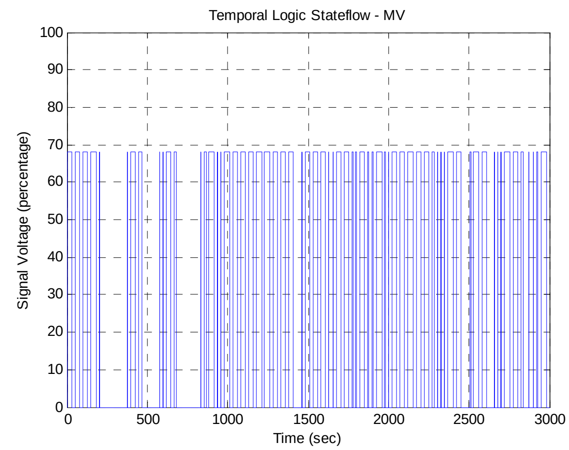

Fig. 9. Control Signal of Temporal Stateflow Control

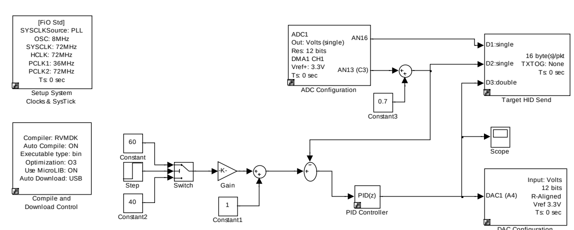

Fig. 10. PID Control Simulink Diagram

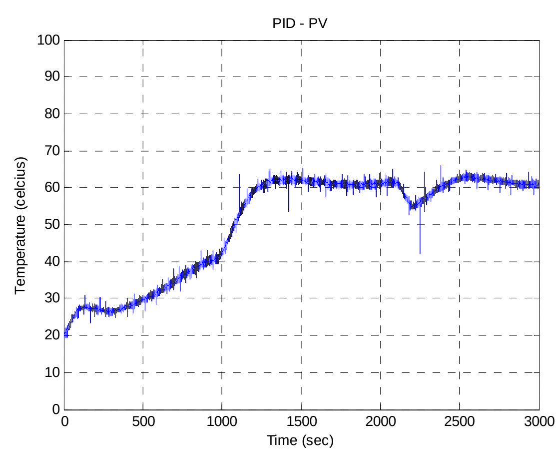

Fig. 11. Step Response of PID Control

ISBN: 978-988-19251-7-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

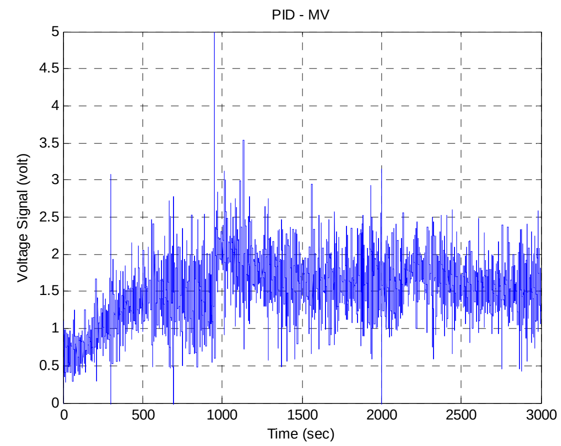

Fig. 12. Control Signal of PID Control

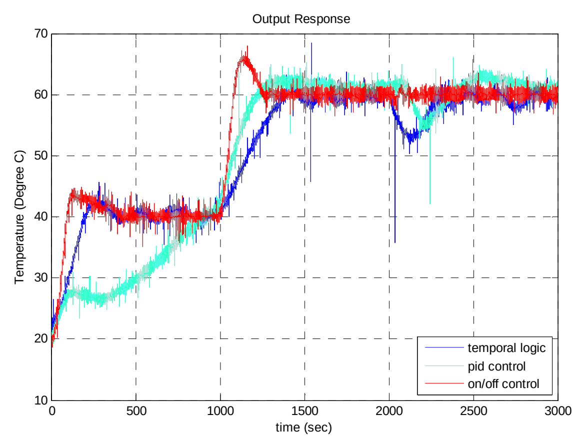

Fig. 13. Comparison for Step Response between On-Off Stateflow, Temporal Logic and PID Control

TABLE I
THE COMPARISON OF OUTPUT RESPONSE

	On-Off Stateflow	Temporal Logic	PID
% M.O.	10 %	0 %	5 %
t_s (sec)	240	360	550

V. CONCLUSION

This study has presented the design of temporal logic embedded controller for small oven process. The performance of control system was tested with Fio board, STM32F103RE ARM 32-bits microcontroller and Simulink program. The results have been shown that Temporal Logic control has control performance higher than simple On-Off Control, and it is comparable with performance of PID control. Thus Temporal Logic algorithm will be another solution for embedded control systems that require both control performance and affordable costs.

ACKNOWLEDGMENT

The author would like to acknowledge her sincere thanks to the Industry/University Cooperative Research Center in Data Storage Technology and Application, King Mongkut's Institute of Technology Ladkrabang and National Electronics and Computer Technology Center, National Science and Technology Development Agency.

REFERENCES

[1] William k. Roots and Jack t. woods, "On-Off Control of Thermal Processes", IEEE Transactions on Industrial Electronics and Control Instrumentation, Vol. IECI-16, No. 2, September 1969.

[2] William k. Roots and F. Walker, "Discontinuously controlled thermal processes," J. Inst. Fuel, vol. 37, pp. 397-414, September 1964.

[3] William k. Roots, "Fundamentals of Temperature Control", New York Academic Press, 1969.

[4] Hadas Kress-Gazit, "Temporal-Logic-Based Reactive Mission and Motion Planning", IEEE Transactions on Robotics, Vol. 25, No. 6, December 2009.

[5] The MathWorks User's Guide, "Real-Time Workshop® For Use with Real-Time Workshop Embedded Coder", Version4, July 2010.

[6] Il Moon, Gary J. Powers, Jerry R. Burch and Edmund M. Clarke, "Automatic Verification of Sequential Control Systems using Temporal Logic", American Institute of Chemical Engineers Journal, November 1991.

[7] William G. Wood, "Temporal Logic Case Study", Technical Report, Software Engineering Institute Carnegie Mellon University, August 1989.

[8] Prof. Bernd Finkbeiner, Ph.D., "Embedded Systems– Stateflow Tutorial", Reactive Systems Group Saarland University.

[9] Sara L. Uckelman, "Temporal Logic", Institute for Logic, Language, and Computation, February 26, 2010.

[10] Nicholas Rescher and Alasdair Urquhart, "Temporal Logic", Springer-Verlag Wien New York, 1971.

ISBN: 978-988-19251-7-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)