International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2000-000X
Vol. 3 Issue 1, January – 2019, Pages: 33-41

Design of Temperature Control System for Infant Incubator using Auto Tuning Fuzzy-PI Controller

Sumardi[1], Darjat[2], Enda Wista Sinuraya[3], Rahmat Jati Pamungkas[4]

Electrical Engineering Department, Diponegoro University
Semarang, Indonesia
1sumardi.undip@gmail.com, 4rahmat.pamungkasjati@gmail.com

Abstract— *Premature birth or low birth weight (LBW) is predictor of infant morbidity and mortality. Generally, infant with premature birth will be treated on incubator device. Incubator must provide stable levels of temperature, relative humidity and oxygen concentration. Temperature on infant incubator must be maintaned around 36°C-38°C. In order to control that, adaptive Fuzzy- PI controller is proposed and implemented on infant incubator's prototype. This research use DHT11 sensor as sensing element and the control method are actuated by lightbulbs. The controller used Microcontroller Atmega16 as processor which output determines the amount of power supplied to the lightbulb by employing pulse width modulation and MOSFET triggered circuit. Tests were carried out on temperature references that correspond to the standard incubator temperature range of 36°C to 38°C. References changes (fluctuatif reference) test and disturbances test were also carried out to prove system performance. The tests result on fixed reference temperatures were able to reach a stable setpoint with time rise (tr) around the 200 second with the highest overshoot maximum steady state error below 5%. References change tests and disturbances test successfully proved the controller was able to follow changes in references and overcome the disturbances.*

Keywords— Atmega16 Microcontroler, DHT11 Sensor, Fuzzy-PI Controllers, Infant Incubator.

1. INTRODUCTION

Premature birth and low birth is one of the major problem all over the world. In indonesia, based on Indonesia Demo-graphic and Healh Survey in 2012 the number of neonatal death is 19 death / 1000 lifeborn babies [1]. This high num-bers represented how premature babies extremly need to be treated carefully and in proper condition. Premature and low birth infants do not have the ability to regulate tempera-ture and produce heat, because they don't have a fully de-veloped thermal regulatory center, as a result of prematurity [2].Infant incubator is a device which attempts to create the necessary environment for the baby's survival. It control the temperature, relative humidity and oxygenation. Temperature is one of the most important parameters that need to be maintained [3]. The other problem is that incubator device reaquires really high cost in use and its really impractical in developing nation like indonesia [4].Therefore to provide suitable environment for infants especially premature born infants temperature, it requires controller which can withstand disturbaces, low tolerance in ocilation, and cheap in design an use.

Many research and development about temparature controller design for infant incubator have been researched. They used various controller design such like On-Off controller ,PID, PI and Fuzzy Logic [5],[6],[7]. All of this research was designed with different component control and heat transfer mechanism. This research propose adaptive control method using fuzzy logic to tune Proportional Integral (PI) Controller parameter as the main controller. Adaptation mechanism are hoped to hold temperature on its stability when the plant got disturbance.

2. REASEARCH METHOD

2.1 Standard And Mechanic Design

Standard infant incubator tempererature used in this paper was taken form the Health Ministrty of Republic Indonesia by decission letter 118/ MENKES/ SK/ IV/ 2014 about Health Equipment Compendium [8]. The standard design of infant incubator device used from the previous research by Faishol Fathur Riza [5]. It contain 3 subsystem, the base part is designed for electronic and power supply, the second part (middle part) are used as actuator box for temperature and humidity, the third part is chamber part (top part) wihich is designed with 3,3 mm transparent acrylic contain sensor and a room to lay the infant. The detail of the mechanic design are showed in Figure 1.

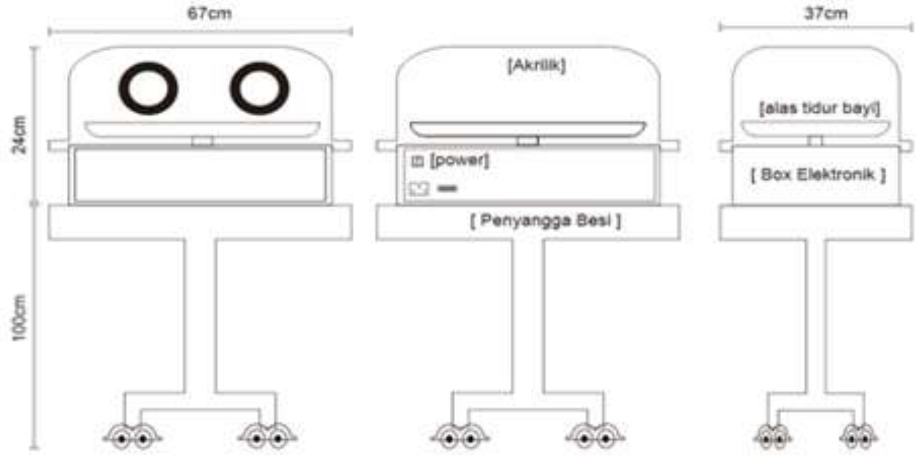

Fig 1. Mechanic design of infant incubator

2.2 Electronic Hardware Design

This part contain electrical palnnning and electronic system design for incubator device. The temperature controller hardware design are exposed in Fig 2.

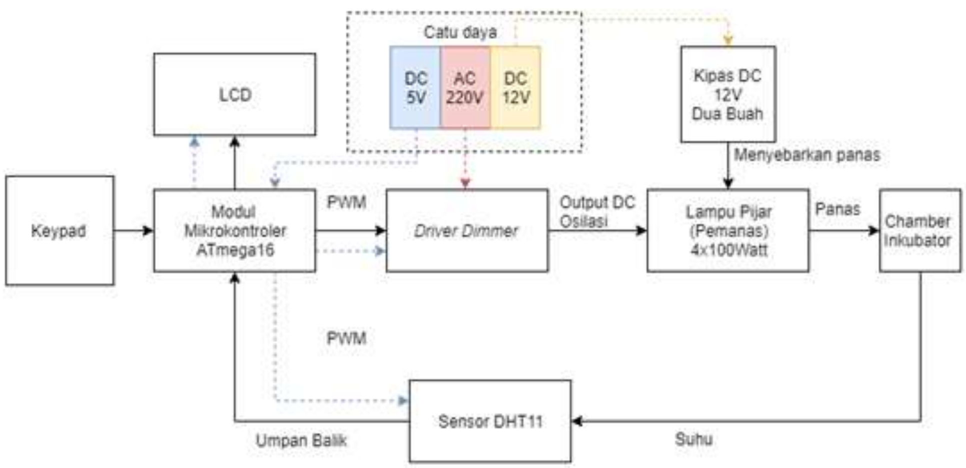

Fig. 2. Block diagram electronic hardware for incubator temperature control

The spesification of the system are listed below :

1. Keypad are used as a input device to select mode and input the setpoint to be processed inside the processor. The processor used in this research is ATmega16 which is programmed with C language. This device execute the fuzzy-PI control program to be actuated by the actuator.
2. LCD display is used as display temperature detection and process that still on going. LCD display 20 x 4 character digitally.
3. Dimmer was used as voltage controller whose consumed by the lightbulb as an actuator.This device activated by pulse width modulation (PWM) signal which trigger the MOSFET to control the output power voltage.
4. Lightbulb used in this paper as a heating element. It is placed in actuator box in the midlle subsystem.
5. DC fan 12V is used to spread the heat from the actuator box to infant incubator chamber
6. Chamber incubator is the plant that is needed to be controlled.
7. DHT11 Sensor detect the temperature and humidity inside the incubator chamber. The data transffered to the microcontroller and showed in LCD display. It use one wire mechanism aqquire data.
8. The voltage needed in this design is AC 220 V for supplying the lightbulb, DC 12 V for suplying the DC fan, DC 5 V for supplying microcontroller, sensor, and LCD.

2.3 Controller Design

This part contain design of Fuzzy- PI controller and its algoritm. Design of Fuzzy-PI controller include process evaluation, fuzzifikasi rules, decision-making mechanisms, and defuzification [9]. Figure 3. shows the Fuzzy-PI control mechanisms that will be used in controlling the temperature in the infant incubator prototype.

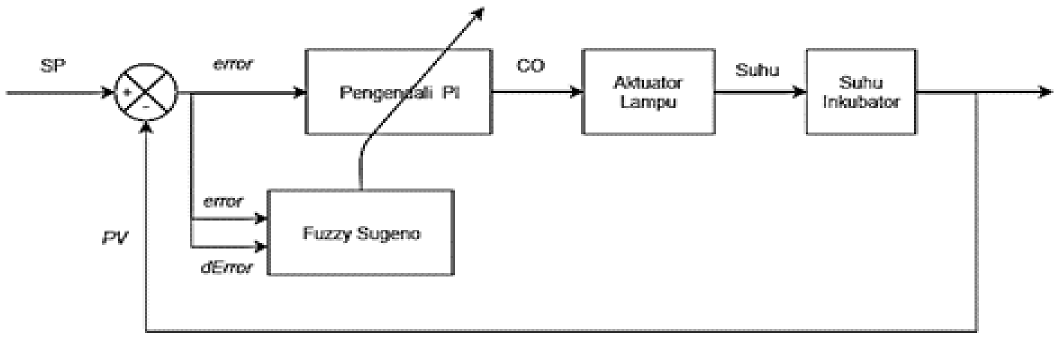

Fig. 3. Block diagram Fuzzy-PI controller mechanism

The control system use fuzzy logic mechanism to tune the main controller PI. Therefore the output of controller must be a constant. Fuzzy Sugeno method are the method for outputing fuzzy as contant or linear equation. It accomodate the system to get Proportional parameter and Integral parameter to get constant value. The fuzzy logic process are shown in Fig. 4 [10].

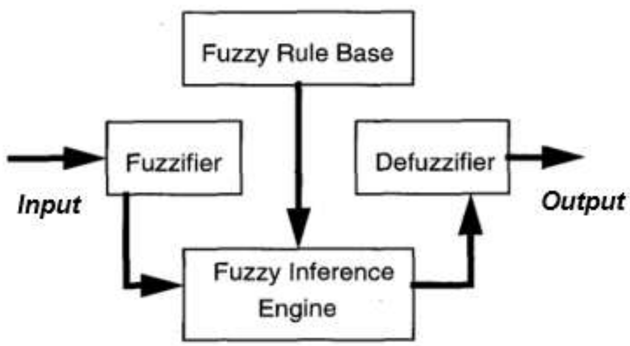

Fig. 4. Basic fuzzy logic process

The first step in designing Fuzzy- PI controller is defining the input membership fuction. In this research error and Δerror are used as the the input. The setpoint and actual value determine the amount of error and Δerror as it can be found in Equation. 1 and Equation. 2.

$$Error(e) = Set\ Point\ (SP) - Actual\ Value\ (PV) \quad (1)$$

$$Delta\ Error\ (\Delta e) = Error\ (e) - Previous\ Error\ (e\ (k-1)) \quad (2)$$

The value of error and Δerror from the crips value fuzzified in fuzzification process. The membership function of error and Δerror are showed in Fig. 5. and Fig. 6. below.

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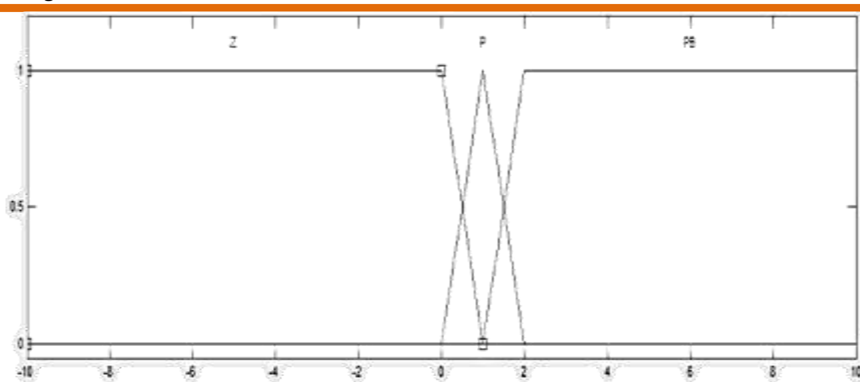

Fig. 5 Membership fuction of error

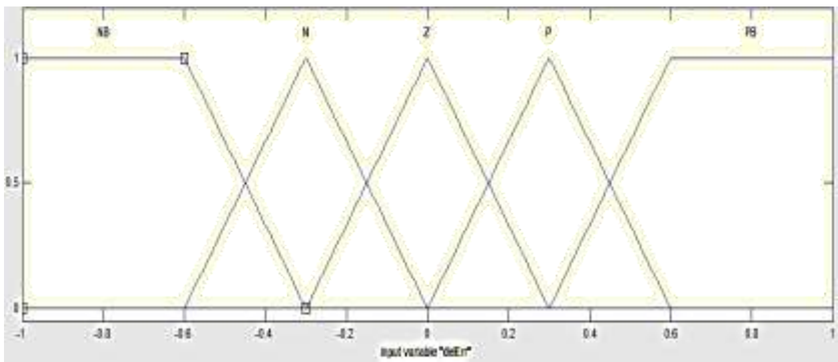

Fig. 6 Membership fuction of Δerror

The error are divided in three membership function there are Z (Zero), P (Positive) and PB (Positive Big). Then Δerror are divided in five membership function there are NB (Negative Big), N (Negative), Z (Zero), P (Positive) and PB (Positive Big). The degree of membershipsed is from 0 to 1. The degree of membership isobtained through the mathematical equation of trapezoidal or triangular membership function. The output of the fuzzy are designed in two singleton function that are shown in Fig. 7 and Fig. 8.

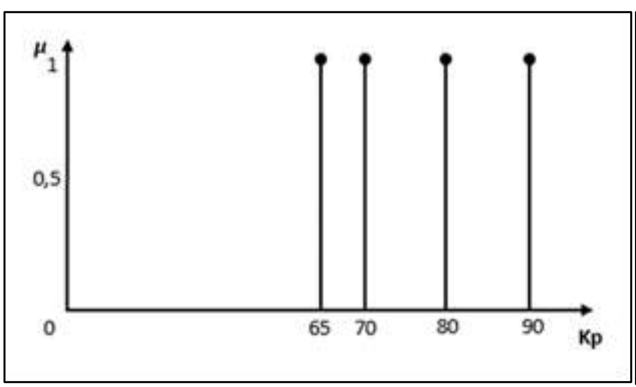

Fig. 7 Output membership function for Kp

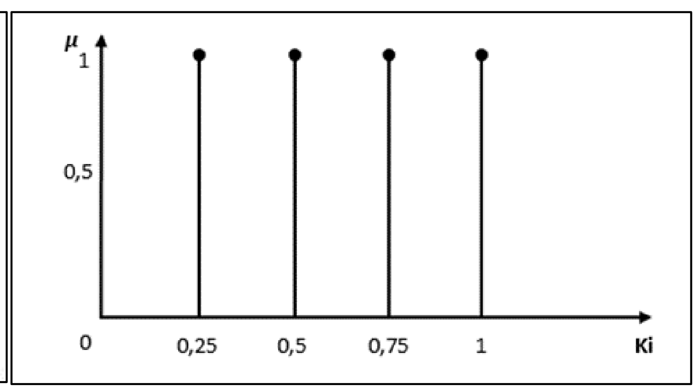

Fig. 8 Output membership function for Ki

The rule base explian the relation between input and output. It is designed by heuristic method, where the rules base are obtained from the analysis of the effect of PI parameters on the transient response of the system to obtain the desired system response [11].The rules are stated in IF- THEN sentence consist input parameter as the cause and output parameter as the effect. Based on the input membership function and the output singleton there are resulted 15 rules that are shown on the Table 1 and Table 2.

Table 1: Fuzzy logic rules for proportional constant (Kp) output

ΔError / ***Error***	**NB**	**N**	**Z**	**P**	**PB**
Z	PK	PK	PK	PS	PS
P	PS	PS	PB	PB	PB
PB	PSB	PSB	PSB	PSB	PSB

Table 2: Fuzzy logic rules for Integral constant (Kp) output

ΔError / ***Error***	**NB**	**N**	**Z**	**P**	**PB**
Z	IK	IK	IK	IK	IS
P	IS	IS	IS	IB	IB
PB	IB	ISB	ISB	ISB	ISB

PK, PS, PB, and PSB in order, represent singleton for proportional constant 65, 70, 80 and 90. Meanwhile IK, IS, IB and ISB in order represent singleton integral constant 0.25, 0.5, 0.75, and 1.

The system perform decission making after the rules are defined. The mechanism used Sugeno inference system. The process of obtaining a firm value from the fuzzy set occurs in the defuzzification process. The method used in defuzzification is the weighted average method with the formula as in Equation 3 [12].

$$\sum_{i}^{n} \frac{W_n Z_n}{W_n} \tag{3}$$

Where Z is the result of the rule evaluation process, while Zn is the singleton value on the nth label of the linguistic variable of the output membership function. Wn is the degree of fuzzy output membership. The number of is equal to the number of Wn, that is as many fuzzy sets are designed on the output membership function.

The proportional and Integral controller take the output of defuzzzification process as parameter control . The control process follow mathematical equation that are showed on Equation 4 and Equation 5[12].

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt \tag{4}$$

In discrete form :

$$u(k) = u(k-1) + K_p[e(k) - e(k-1)] + K_i e(k) \tag{5}$$

Where u(k) and u(t) are output controller in discrete and analog, e(t) and e(k) are error function in analog nd discrete, Kp and Ki are parameters for proportional and integral controllers, Then Ti is time integral. The result of computation then feedbacked and compared to the setpoint.

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3. Result and Discussion

System was tested in several stages using Visual C# monitoring temperature software. The system respons tested in three condition. There are respons test in constant references, respons system test for reference changes and disturbance test. The test in constant references result are showed in Figure 9, 10 , and 11.

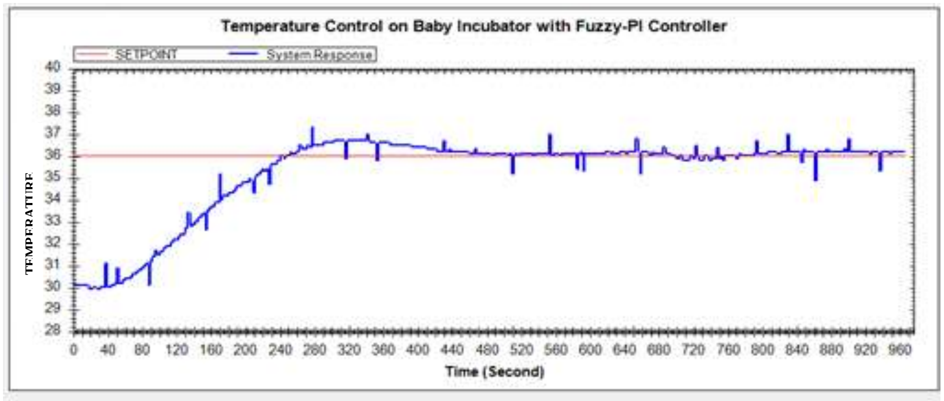

Fig. 9 Respons System test in 36 °C temperature references

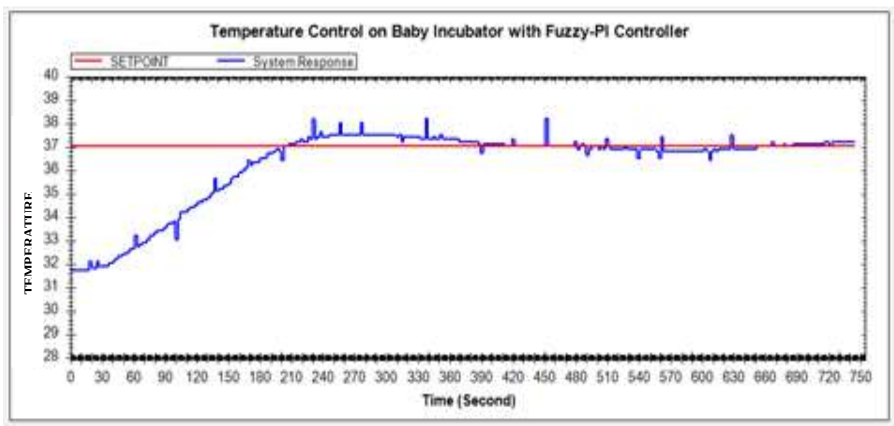

Fig. 10 Respons System test in 37 °C temperature references

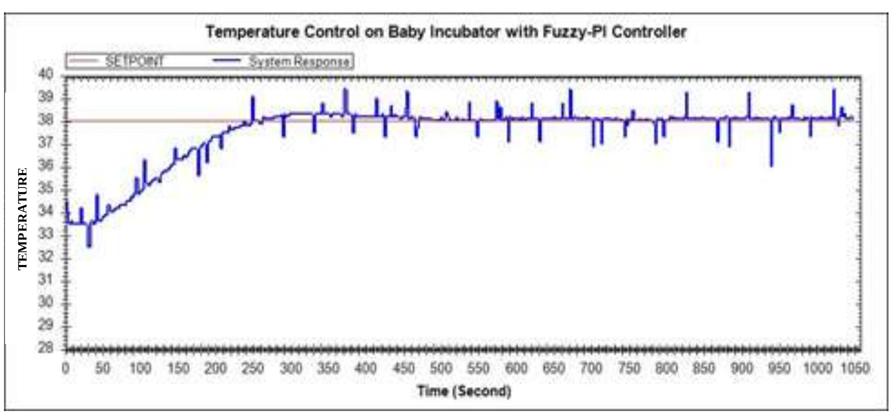

Fig. 11 Respons System test in 38 °C temperature references

Using respons system analysing process it can be elaborated the stability of the control system [13]. The respon system test on 36, 37 and 38 temperature references analysed on the Table 3.

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Table 3: Fuzzy logic rules for proportional constant (Kp) output

References	Time Rise (Tr)	Time Peak (Tp)	Time Settle (Ts)	Maximum Overshoot (Mp)	Error Steady state (Ess)
36°C	250 s	312 s	460 s	1,67 %	0,56 %
37°C	199 s	265 s	372 s	1,08 %	0,2 %
38°C	236 s	318 s	425 s	0,79 %	0,26 %

From the test results system has proven the stability and consistensy in mantaining the temperature condition on the incubator chamber. The little Error steady state percentage prove that fuzzy PI controller has minor ocilation in maintaning temperature condition.

The next stage of test in respons sytem is test wits references change (fluctuate reference). Reference was change three times up and down. The result showed on Figure 12.

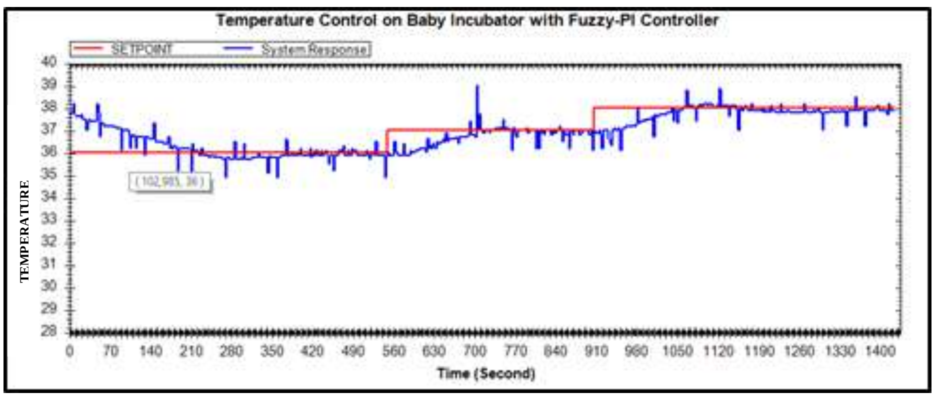

Fig. 12 Respons System test with reference changes

The purpose of reference change test is for the system is to prove the system can follow the change of references.According to the Figure 12 it was proven that the system can follow change stably. Three times chnge of references aquired and maintained by the controller with minor error steady state and overshoot.

The final test is disturbances test to test the system consistency by the change environment control plant. Disturbance for the incubator plant was implemented by opening the nursing door. The test result are showed on Figure 13.

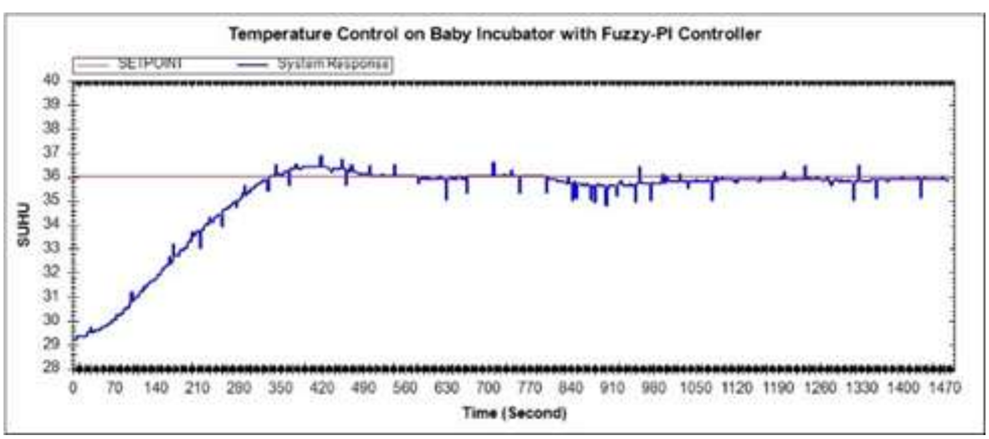

Fig. 13 Respons System test with disturbance by opening nursing door in second 770.

Based on the graph of the system response with the disturb-ance in Figure 4.17 it can be seen that the disturbance is giv-en at 770 seconds. Giving interference makes the system re-sponse drop below the setpoint with the lowest temperature reached is 35.6 ° C. Then the temperature starts to gradually rise to maintain the temperature conditions at the reference 36 ° C. The system is able to reach a 36 ° C setpoint at 1096 seconds, the remaining temperature rises and falls at 35.8 ° C to 36 ° C. From the results of testing the response of the system with interference, it can be concluded that the fuzzy-PI controller is able to work well in response to the interfer-ence provided so that interference can be reduced and can restore the system response to reference 36 ° C. The duration of system recovery from interference is around 326 seconds.

4. Conclusion

Fuzzy-PI controller has been designed to control tempera-ture in infant incubator prototypes that are able to control the temperature at the standard reference temperature of the baby incubator. The system can follow the reference changes and maintain the temperature stability on reference respectively. The system is able to stabilize and return the system response to the desired temperature reference after previously dropping to 35.6 ° C, with the recovery time to-wards a steady state of 36 ° C for 326 seconds.

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Authors

Sumardi, born on November 11th 1968 in Sukoharjo, Central Java. Graduated as a bachelor in Diponegoro University, Semarang, majoring in Electrical Engineering, Faculty of Engineering, in 1994. Got a master degree in 1998, majoring Instrumentation and Control Engineering Physics Program, Institute of Bandung Technology. Current business is as a lecturer and researcher at Electrical Engineering Department, Faculty of Engineering, Diponegoro University, Semarang, Indonesia

Darjat, receive Bachelor degree in Diponegoro University Semarang majoring electrical engineering, Then got a Master degree in engineering at Gadjah Mada University, Indonesia . He has been a lecturer at the Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia since 1999. His research interest are in electronics and microprocessing

Enda Wista Sinuraya, born on December 1980, receive barchelor degree in Sumatra Utara University in 2006, graduate with Master degree in enggineering at Indonesia University in 2010. He has been a lecturer at the Department of Electrical Engineering, Diponegoro University, Semarang, Indonesia since 2010. His research interest are in Control engineering and IT

Rahmat Jati Pamungkas, born on March 21th 1997 in Purworejo, Central Java. Graduated in from State Elementary School 1 Sucenjurutengah , State Junior High School 4 Purworejo, State Senior High School 7 Purworejo and bachelor in Diponegoro University, Semarang, majoring in Electrical Engineering, Consentrate Instrumentation and Control Engineering in 2018.