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The Robust PID Control System of Temperature Stability and Humidity on Infant Incubator Based on Arduino AT Mega 2560

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Abstract. Premature babies have a high level of sensitivity that one of them is toward temperature and humidity of the surrounding environment. Therefore special treatment is required for premature babies. Related to it the babies required infant incubator to stabilize the temperature and humidity around the baby's body. To control temperature stability at 36 ° C and humidity at 80% - 60% RH value in incubator space required Arduino Mega 2560, Arduino Uno, LM35 sensor, DHT22 sensor and added PID control (Proportional Integral Derivative) to reduce maximum overshoot (Mp) and error signal average $\leq$ 5% and speed up the system to reach the setting point. With the PID control the maximum overshoot value Mp = 0.833889%, the error signal average e = 0.011033% and the temperature reached steady level at the 218 seconds on testing the infant prototype without load.
 Keywords: Infant Incubator, Robust PID control, Temperature, Humidity, Arduino

1.Introduction

The history of infant incubator development was started in the early 20th century. The complex problems was a challenge of professional of medical technology [1]. The development of technology in the field of health has happen very quickly, without exception in the treatment of newborns. However, the quick development of technology is considered less evenly perceived only by developed countries and some developing countries. As a result, in some developing countries reported the highest Infant mortality rate. Infant mortality rate in Indonesia is reported to be the highest occurrence of some ASEAN members (Association of Southeast Asia Nation) which is 4.6 times higher than Malaysia, 1.3 times higher than the Philippines, and 1.8 times higher than Thailand [2].

One of the factors to contribute to high Infant mortality rate in Indonesia are babies born prematurely. Premature-born infants require special treatment, especially in maintaining the stability of the surrounding environment temperature. The temperature of premature infants should be kept as the baby is in the womb that is between 35˚C- 36˚C. To get the temperature of the environment in such a way, babies born prematurely should be treated immediately by an incubator. According to Harseno, 2017, Infant incubator is a tool that has the function to prevent hypothermia or conditions where the body difficulty to regulate cold temperature pressure in newborn babies especially premature babies or have low birth weight (BBLR) by warming the room temperature to be able to maintain baby's normal

temperature [3]. In Afiffah et al, 2008, the trend of Infant Mortality Rate (IMR) per 1000 live births based on Susenas 1998, 2001, 2003 according to the background characteristics of residence areas. In urban areas in 1998 there were 35 per 1000 live births, in 2001 decreased to 39 per 1000 live births, as well as in 2003 there were 29 per 1000 live births [1]. While in rural areas in 1998 there were 56 per 1000 live births, in 2001 increased to 59 per 1000 live births and in 2003 there were 48 per 1000 live births. Based on the information that researchers get, some general practice (GP) in rural or purlieus still use local production incubators which are still manual in nature, where the nurse must remain standby on monitor the temperature periodically by using the existing thermometer in the incubator. The manual incubator is very risky for babies born prematurely, because negligence or human error is very likely to occur which leads to decreased treatment quality in newborn care, especially babies that born prematurely.

Previous research that conducted by Widhiada, et al, 2017 on Temperature Distribution Control of Infant Base Incubator System based Arduino ATmega 2560. In his research using heating element as heat source with the application of on / off control it takes 400 seconds to reach temperature 36˚C [4].

In this research, incubator modeling was carried out both an Arduino Mega 2560 microcontroller and an Arduino Uno microcontrollers. These microcontrollers are integrated with each other with the help of filters made of Electrolite Condensor 22 μF, 25 volts which were assembled into a single unit with a 2 kilo ohm Resistor.   The PID control is applied to control the incubator system with MATLAB/Simulink software. The block diagram of Simulink is part of MATLAB for technical calculations and control design. When designing of a baby incubator prototype is ready with an Arduino microcontroller, therefore PID control is used to regulate the temperature to remain stable at 36˚C and humidity 60-75% RH. PID controllers are widely used in industry [5]. Each control action has certain advantages, where the action of proportional control has the advantage of fast rise time, the action of control integral has the advantage of minimizing errors, and the action of derivative control has the advantage to reduce signal error or reduce overshoot / undershoot [6]. Some of the advantages above are expected to apply PID control to make the system performance stable and able to accelerate the reaction of a system to reach its set-point. So that the premature baby incubator has an automatic and stable temperature control as desired

2. Methods

2.1. Description of research

In the designing of this incubator which consists of two main parts of the upper box and the lower box of the incubator. In the lower part of the box consists of Arduino Uno board, Arduino Mega, incandescent lamp, relay, AC light dimmer, adapter and fan while the upper of the incubator consists of DHT 11 temperature sensor, LM 35 temperature sensor, incubator mattress, and incubator cover. The size of the incubator geometry is length = 65 cm, width = 45 cm, and height = 45 cm. 3D baby incubator design can be seen in the picture below.
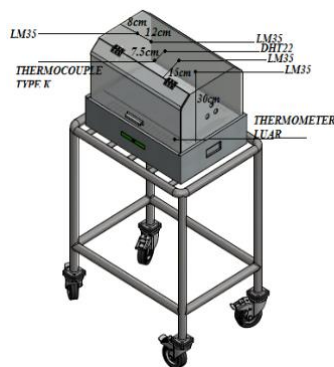

Figure 1. The design of a baby
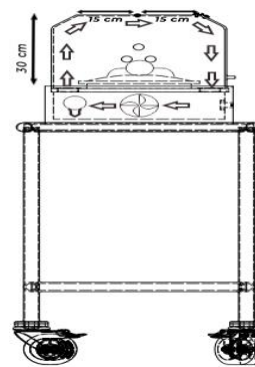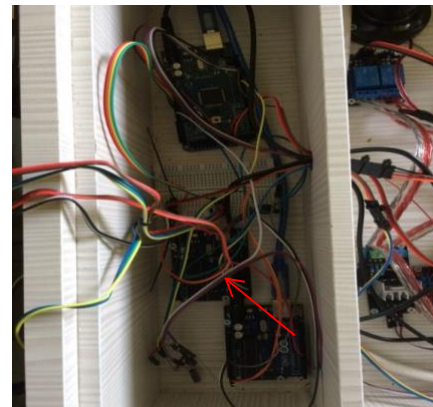

Figure 2. Schematic of air

incubator 3D model.　　　　　　　　　　circulation infant incubator.

Figure 3. Design box under baby incubator.

Figure 4. Design of the incubator box complete with the sensor.

Acrylic is a glass-like plastic, but it has characteristics that make it superior to glass in many ways and one of the different characteristics of the acrylic flexibility itself. Acrylic is easy to process like cutting, filing, drilling, smoothing and difficult to be broken like glass. The acrylic type which used in this research is a clear aqueous type used on the upper of the incubator. Multiplex is a board made of layered plywood. A stronger multiplex surface layer aims to protect the multiplexed inner layers that the bending and expansion process can be reduced well.

The Arduino mega 2560 is an ATmega2560 microcontroller board that has 54 digital input / output pins (which 15 can be used as PWM output), 16 analog inputs, 4 UART (serial hardware port), 16 MHz crystal oscillator, USB connection, power jack, ICSP header, and the reset button [7].

Arduino Uno R3 is a minimum system board based on AVR type ATmega328 microcontroller. In Arduino Uno R3 has 14 digital input / output (6 of which can be used for PWM output), 6 analog inputs, 16 MHz crystal oscillator, USB connection, power jack, ICSP header and reset button.

The DHT 22 sensor is one of the temperature and humidity sensors, also known as the AM2302 sensor. Temperature sensors are required to inform the output signal as feedback on the controller. LM35 type temperature sensor is a sensor in the form of an integrated circuit that has precision, where the output voltage is linear by depending on the temperature in Celsius degrees.

The incandescent lamp is used as a heater in the infant incubator room. Consider the function of the incandescent lamp is emitting light and heat. Researchers used 3 pieces of 100 watt incandescent lamps that mounted parallel to the distance of 10 cm from each lamp, because the main purpose of this research is to find a system that quickly reaches its set point temperature.

This module is designed to control the intensity of light in an incandescent lamp where the working principle is the PWM (Pulse Width Modulation) signal setting where pulse width modulation (PWM) is

obtained by the help of a square wave in which the duty cycle of the wave can be altered to obtain a varying output voltage which is the average value of the wave itself, so that the intensity of the light of an incandescent lamp may change to light or dim.

Fan is used to distribute the heat and cold if the temperature is above the setting point and humidity value is at set point value. Adapter / Power Supply is a DC voltage source. The DC voltage source is used to provide the input voltage for the circuit block with the voltage and appropriate flow to the circuit requirements themselves.

Relay is an electronic switch that can open and close the circuit by using control of another electronic circuit. In the initial design the microcontroller will send a signal to the relay to disconnect or connect the electric flow to the heater (incandescent lamp).The L298N Motor Driver is the most widely used motor driver to control or manage the speed and motion of DC motors. Where this motor driver has the same working principle as AC light dimmer it is setting the PWM signal (Pulse Width Modulation) so that it can control the desired fan speed.

LCD's (Liquid Crystal Display) functions are to display numbers of characters, numbers, letters and symbols with better and with low flow consumption. Filter serves as a bridge between Arduino Mega microcontroller and Arduino Uno. The working principle is to change the output signal from Arduino Uno in the form of Digital signal into Analog signal which becomes Input from Arduino Mega. This filter is made of Electrolyte Condensor 22 μF, 25volt which is assembled into one unit with 2 kilo ohm Resistor.

2.2. The strategy of incubator control

The researchers has used PID controls to accelerate the response of temperature controller system and moisture to achieve its set point temperature. This control is the most important substance in the distribution of control systems and also often integrated with simple logic, sequence functions, selectors, and functional blocks used to create more complex systems [8]. Temperature adjustment is done by adjusting the amount of light intensity and the heat generated by incandescent lamp on the plant through the provision of AC voltage, that controlled by the AC voltage control circuit. The temperature value as the result of the output produced during the process is then measured by the temperature sensor and is used as feedback input for the PID control of the set point input. Then both variables are processed by the microcontroller. Then the result of the process is used as input on the voltage controller block to determine the magnitude of the intensity of light and heat. In general the system formed is a negative feedback system. Researchers at this time will use the Tuning Trial & Error method to determine the parameters of PID.
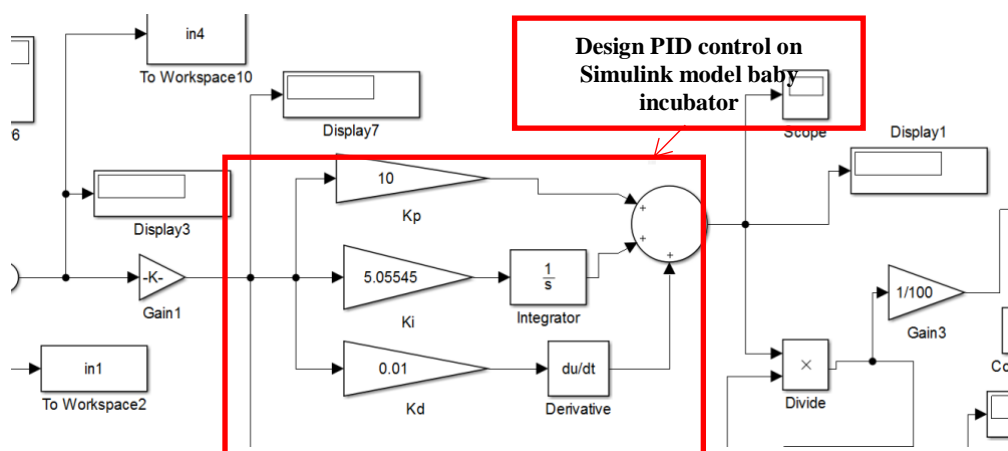

Figure 5. PID control design with the help of Simulink/MATLAB software.

The effect of various of temperature using ethylene-glycol-based TiO2 nanofluid was presented to

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maintain the stability of temperature distribution in material workpiece [9], [10]. However this experiment was limited because the temperature of workpiece was not simulated with thermocouple.

Figure 6 shows the flow cart of the PID control is applied to control the temperature and humidity into infant incubator research. The integration both Inventor (Auto-desk) and MATLAB/Simulink are applied as a power tool to modelling and analysis of incubator system. Inventor is the autocad software which used to draw the incubator system. MATLAB/Simulink is used to create the coding of incubator systems.

Figure 6. The research flow diagram.

2.3. Infant incubator test without load

Non-load Infant incubator test was performed by operating an infant incubator prototype for 36,000 seconds without pause. Testing was intended to see the system on the condition of the morning, afternoon, and night. This research placed four LM35 and 1 DHT22 sensors in the incubator chamber by placing the temperature sensor measuring point at 15 cm from the incubator front plane, 12 cm from the incubator plane, while the height of the sensor 30 cm from the surface area of the material considered to representing all of the incubator surfaces. Set temperature point value at 36°C and humidity setting point at 80-60% RH. If the average temperature measurement of the 4 LM35 sensors is greater or equal to the setting point value then the microcontroller gave an error signal. Comparison of temperature sensor value with setting point will be passed through PID control which then signals error is forwarded toward Digital Output Arduino to give command on Module AC Light Dimmer to turn the incandescent lamp off. The system will form a close-loop system and will repeat continuously according to the duration time setting of prototype setting.
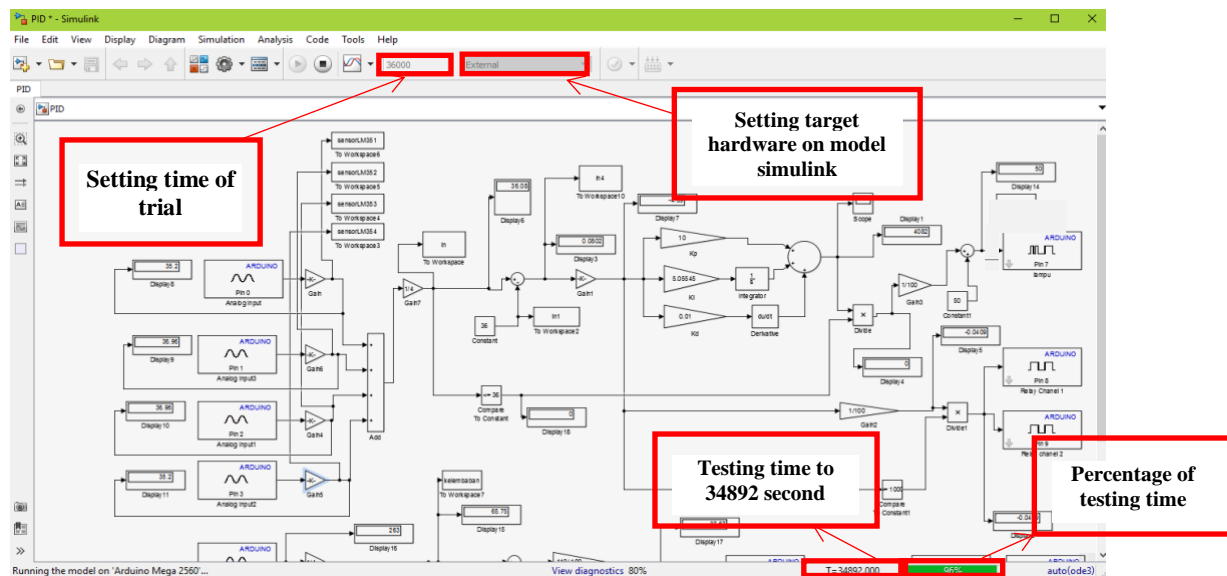
Figure 7. Schematics running asserted prototype testing without load with the help of Simulink/MATLAB software.
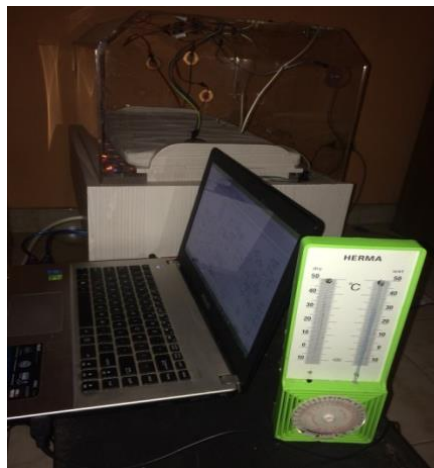

Figure 8. Running testing of incubator prototype without load.

2.4. Prototype testing of infant incubator with 2kg load

Non-load infant incubator test was performed by operating the infant incubator prototype for 36000 seconds without pause by gave 2kg load in order to know the system response when it was loaded at the incubator room.
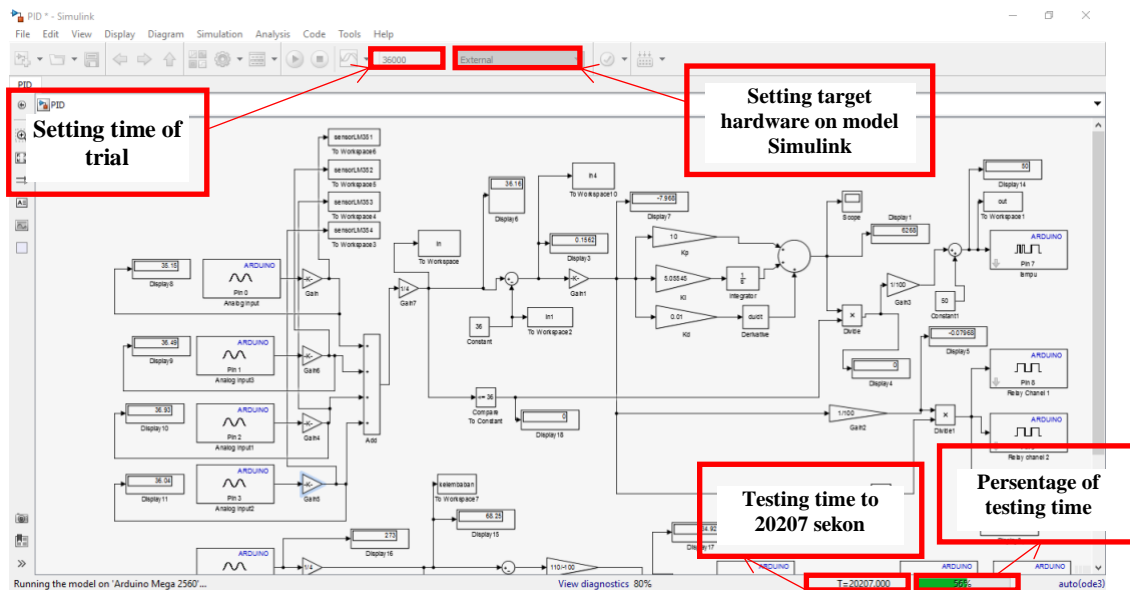
Figure 9. Running scheme of incubator prototype testing with 2kg load with the help of Simulink/MATLAB software.

Figure 10. Running incubator prototype testing with 2 kg load.

3. Results and Discussion

3.1. The results of testing the incubator prototype without load

Figure 11 showed that the blue temperature chart increases from 0 seconds at 30.8002°C, then the temperature chart moved up and steady at the 218 seconds. The rise in the temperature graph is inversely proportional to the humidity graph. In the yellow moisture graph at 0 second can be seen that 78.5% decreased as temperature increased and it start stable at 325 seconds.
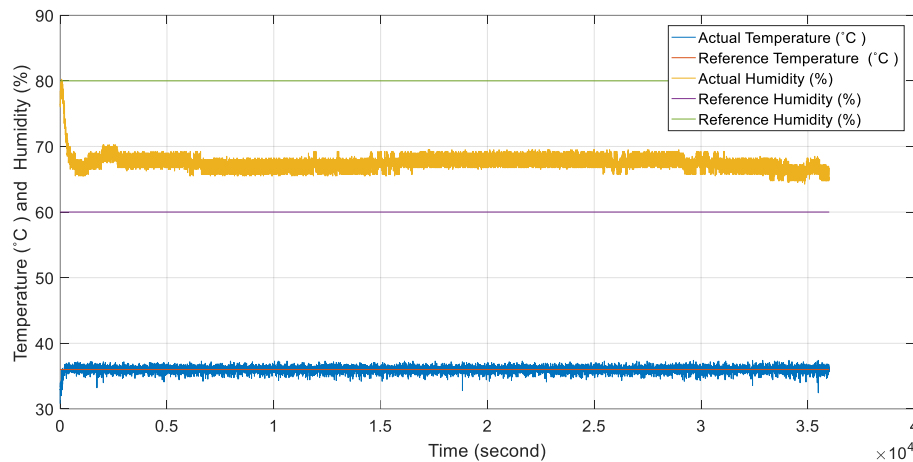
Figure 11. Graph of temperature and humidity connection in incubator test without load.

It is because if the air temperature increased the moisture content of the indoor incubator is reduced, which means the air humidity is also reduced. When the temperature value has stabilized at point setting the humidity graph will also be stable.
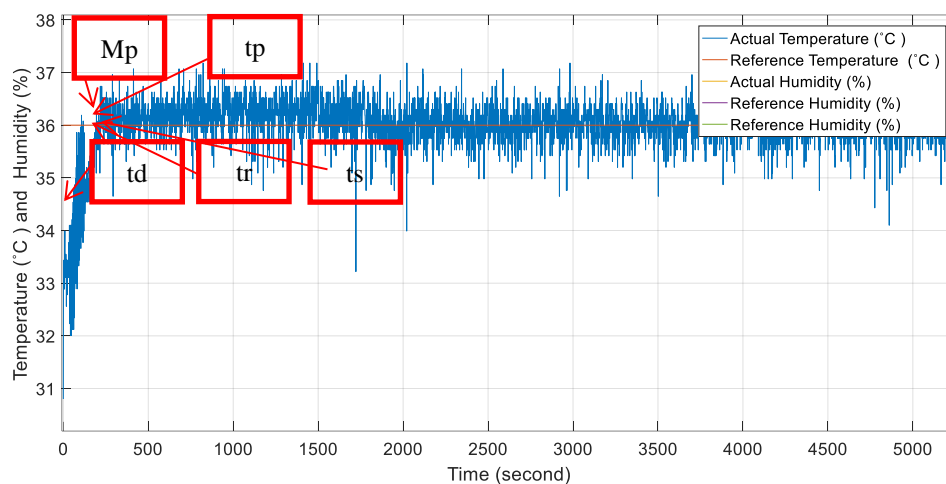

Figure 12. Analysis of system response using Simulink/MATLAB.

In Figure 12 based on the results of system response analysis using simulink / MATLAB software obtained the following parameters:

1. Delay time, td = 96 seconds
2. Rise time, tr = 193 seconds
3. Peak time, tp = 196 seconds
4. Maximum overshoot,

$$Mp = \frac{PV - SV}{SV} \ x \ 100\% = \frac{36,3002 - 36}{36} \ x \ 100\% = 0,8338\%$$

5. Settling time, ts = 218 seconds
6. The average error signal,

$$\bar{e} = \frac{1}{N}\sum_{i=1}^{N}\frac{PV - SV}{SV}x100\%$$

$$= \frac{142,9920044}{36001} = \frac{0,00397889}{36} \; x \; 100\% = 0.011033\%$$
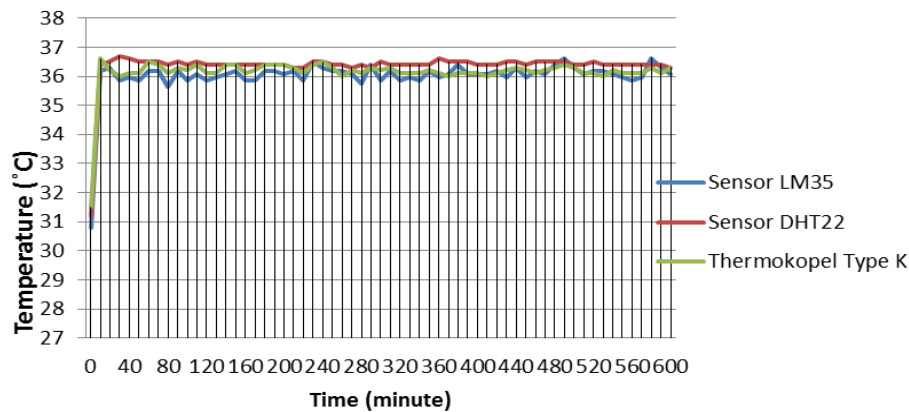

Figure 13. Connection between LM35 Sensors, DHT22 sensor, Thermocouple type K.

For the measurement results in the incubator room using the DHT22 temperature sensor, the LM35 sensor and the indoor thermometer obtained the graphs that described in Figure 4.16 can be seen graphs tend to be the same direction of change but on the red circle DHT22 temperature sensor a little longer to reach its maximum stability point compared to other sensors, it indicates the DHT22 sensor is less sensitive compared to other sensors.

3.2. Result of incubator prototype test with 2 kg load

Figure 14 shows that the blue temperature chart increases from 0 seconds at 31.0387° C, then the temperature chart moves up and stable at 246 seconds. The rise in the temperature graph is inversely proportional to the humidity graph. In the yellow humidity graph at 0 moment can be seen that is 80.75% decreased as temperature increased and it started stable at 420 seconds.
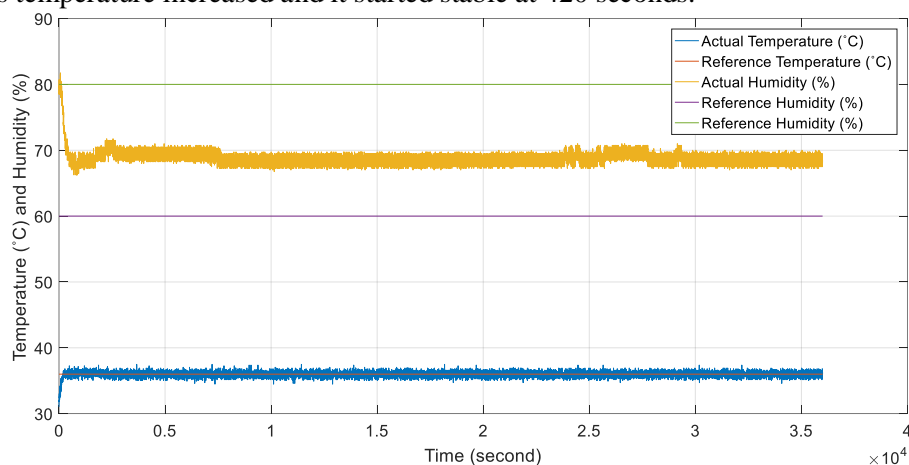

Figure 14. Graph of temperature and humidity connection on incubator testing with 2 kg load.

This is because if the air temperature increases the moisture content of the indoor incubator are reduced, which means the air humidity is also reduced. When the temperature value is stable at the point setting then the moisture graph will be stable too.
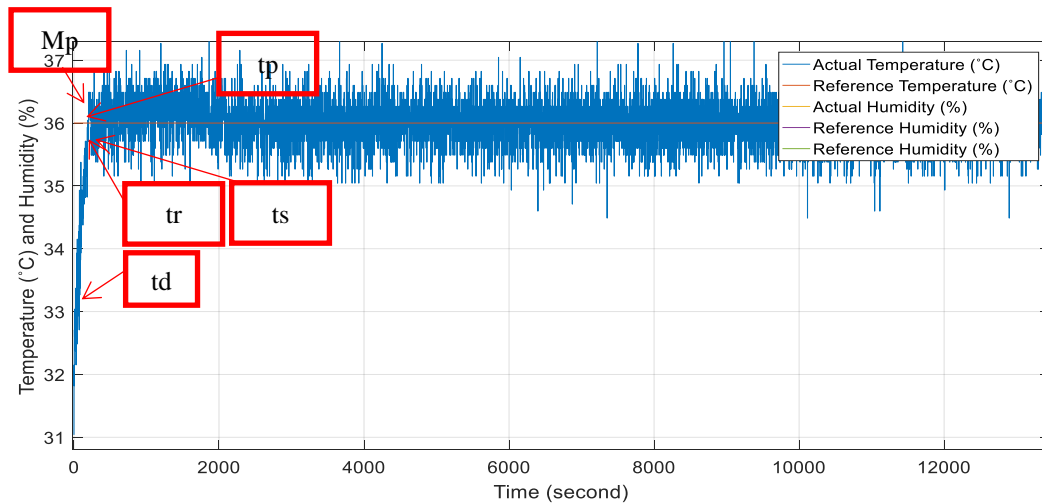

Figure 15. System response analysis using Simulink/MATLAB software.

In Figure 15 based on the results of system response analysis use Simulink / MATLAB software as the parameters as follows:

1. Delay time, td = 86 seconds
2. Rise time, tr = 203 seconds
3. Peak time, tp = 205 seconds
4. Maximum overshoot,

$$Mp = \frac{PV - SV}{SV} x \ 100\% = \frac{36,4900 - 36}{36} x100\% = 1,36111\%$$

5. Settling time, ts = 242 seconds
6. Average error signal,

$$\bar{e} = \frac{1}{N} \sum_{i=1}^{N} \frac{PV - SV}{SV} x100\%$$

$$= \frac{390.1769905}{36001} = \frac{0.01083794}{36} x100\% = 0.030105\%$$
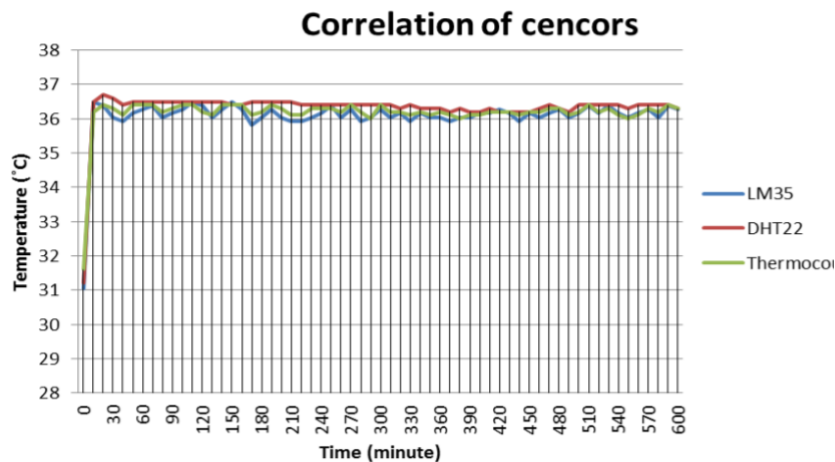
Figure 16. Connection between LM35 Sensors, DHT22 sensor, Thermocouple type K.

In Figure 16 on the red circle the DHT22 temperature sensor is slightly longer to reach the peak point than the other sensors. It denotes the DHT22 sensor is less sensitive than the other sensors it also looks at the red circle tends to change slightly while other sensors experience fluctuations

4. Conclusions

Based on the test results that have been done can be concluded that:

1. By adding PID control to Simulink model of infant incubator prototype without load and with 2 kg load obtained the value of Mp (Maximum Overshoot) = 0,8338% in incubator test without load while MP value (maximum Overshoot = 1,3611% in infant incubator test with add 2 kg load.

2. With the addition of PID controls on the Simulink model of infant incubator prototype without load and with a load of 2 kg can be obtained mean error signal e = 0.011033% in infant incubator inflation test and average error signal e̅ = 0.030105% on infant incubator testing with 2 kg load.

3. By adding the PID control the system response is faster to achieve the point setting value and can minimize the maximum overshoot ≤ 5% and the average error signal e ≤ 5%.

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