A Simple Method for Calibration of Temperature Sensor DS18B20 Waterproof in Oil Bath Based on Arduino Data Acquisition System

R. A. Koestoer[a)], Y.A. Saleh, I. Roihan, Harinaldi

Heat Transfer Laboratory, Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia Kampus Baru – UI, Depok, 16424, Indonesia

Corresponding author: [a)]koestoer@eng.ui.ac.id

Abstract. The combination between DS18B20 Waterproof temperature sensor and Arduino has been recently used as a data acquisition (DAQ) system on a temperature measurement for its user-friendly and relatively affordable price. Arduino can be a valid data acquisition device if the sensor is perfectly calibrated. This research proposed a calibration method for a temperature sensor DS18H20 Waterproof based on Arduino Uno using a thermometer calibrator ASTM 117C which value could be traced by a calibration medium of oil in an open surface bath. The election of oil as the medium is aimed to reduce its conditional instability so that the calibration could be done. There are 12 arranged DS18B20 waterproof sensors that will be calibrated alongside the ASTM 117C calibrator so that all the measurement points have the exact identical conditions. Such a system was done for having the small deviation characteristics between the oil temperature measured on the DS18B20 Waterproof sensor to the ASTM 117C mercury thermometer. The small deviation characteristics that presented as a linear equation is obtained by using a linear regression method. Calibration was done by using the ambient temperature as the energy to calibrate the sensors. The movement of ambient temperature will cause temperature slowly movement response on the medium (oil) and resulted a measurement points. DS18B20 waterproof sensors resulted a mean error of ± 3.00 % before calibration begun. Meanwhile after the calibration using the proposed method, the DS18B20 sensor has a smaller mean error of ± 0.85 %, so that obtained a more accurate sensor and it can be used for testing of Grashof Portable Incubator made by University of Indonesia.

INTRODUCTION

Temperature is one of the main parameters in a baby incubator. In this research, the author made data acquisition system for temperature measurements based on Arduino combined with DS18B20 Waterproof temperature sensors. Arduino has good reliability, robustness, stable connection, low price and can be used as a system control from various levels of system complexity [1]. Arduino can be a valid acquisition data device if the sensor is properly calibrated [2]. Researchers have used a combination of DS18B20 Waterproof sensors with Arduino because of their easy use and relatively inexpensive device prices. Nevertheless, not many know the effect of the error level generated by the sensor. In case of measurements with small measurement range, the error value will have a significant effect, such as on a baby incubator that has a working range 3 ℃ - 4℃. Therefore, calibration method is proposed to calibrate the DS18B20 Waterproof sensor using oil bath with ASTM 117C thermometer calibrator that has better accuracy and precision. This calibration method aims to reduce error level of DS18B20 Waterproof sensor by using oil bath as a calibration medium compared to ASTM 117C thermometer. With the results of calibration, a sensor that has better accuracy can be obtained. therefore it can create a cheap data acquisition with a trustworthy error value [3].

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METHODOLOGY

Materials

DS18B20 Waterproof sensor operates in range of temperature -55 °C to +125 °C with ± 0.5 °C error at -10 °C to + 85 °C and has an 0.0625 °C acurracy [4]. Linear scale of voltage and temperature of the sensor is +10.0mV/° C [5]. While ASTM 117C thermometer that used as a calibrator has 23.9^{o}C - 30.1^{o}C measurement range with a 0.01 ^{O}C accuracy. Data retrieval is carried out in two different places in order to maximize the measurement range of ASTM 117C considered as true value. First research site`s in Depok, West Java, the measured oil conditions were 25 ° C-30 °C., then data collection is carried out in Lembang, Bandung which has a lower ambient temperature in order to reach the lowest temperature ASTM 117C. After data collection, oil conditions were found in all ASTM 117C measurement ranges. Data collection time in this research can be done at any time and not limited to weather conditions. Changes on temperature movements of this environment will affect oil temperature and obtain measurement points.

Calibration Tool

In this research, the author conducted 3 main stages of research, namely stage of making a calibration tool, calibration process, and analyzing calibration results. First, the author makes a research apparatus to collect data. The calibration tool is arranged as follows:

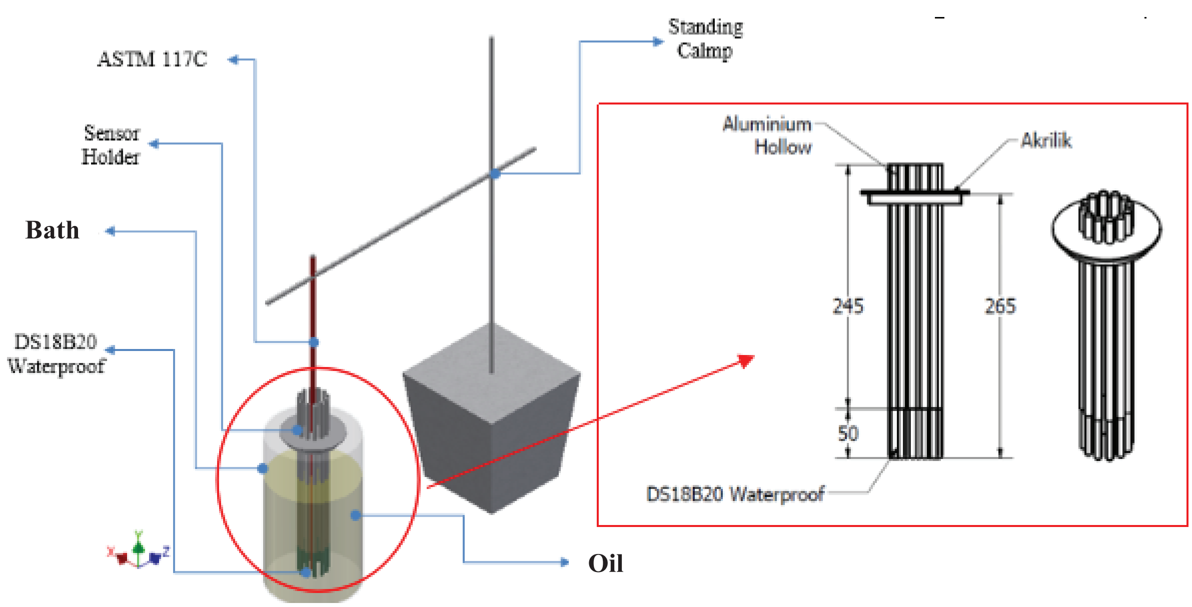

FIGURE 1. Calibration Tool with millimeters unit

The experiment uses Arduino Uno with a maximum of 12 digital input pins that can be utilized with 12 DS18B20 Waterproof sensors at same time. The sensors were immersed in 4 liter volume oil bath together with a ASTM117C mercury thermometer. Oil media selection aims to reduce the instability of the calibration media conditions, therefore calibration can be done [6]. The sensors were arranged in a circle and thermometer is in the center of sensors arrangement so that they were at a parallel depth and measure same conditions.

Calibration Process

The measured data is the temperature of DS18B20 Waterproof sensor automatically carried out by Arduino instead of ASTM 117C and environmental temperature were carried out manually. Date and time of data retrieval also need to be noted therefore data collection has the same measurement conditions. The error values between the sensor and the calibrator will be obtained from those data. Error characteristic was expressed by linear equation obtained from regression. After that, the regression line equation is analyzed by showing the uncertainty parameters such as deviation, confidence interval and coefficient of determination [7]. These parameters serve to express and assess whether the calibration method can be accepted scientifically.

Analyze Calibration Result

Regression line equation then used to find calibration equation using the inverse principle. Calibration equation then entered into Arduino program for calibrating DS18B20 Waterproof sensor reading closed to ASTM 117C temperature that we trust as true value. To prove whether the calibration equation can be used, data is retrieved again with a new calibration program. After that, analyze the error between sensors, % *error* between grouped sensor and thermometer, and the regression parameters before and after calibration.

RESULTS

Data Before Calibration

FIGURE 2 is a graph of oil temperatures from ASTM 117C Thermometers, 12 DS18B20 Waterproof sensors and ambient temperatures before calibration has done. This data is a group of several data collection times. The range of oil temperature data obtained is from 23.9 ° C to 30.1 ° C meet the ASTM 117C working range. In **FIGURE 2** can be shown the temperature data of the environment range is 20 °C-31 ° C. Environmental temperature movements will affect oil temperature and obtain measurement points. Movement from ambient temperature is fluctuating and cannot be controlled. While the movement of oil temperature gives a slow and more stable (non-fluctuating) response not following environmental temperature movements. So that calibration can be carried out under these conditions. This was corresponded with the aim of selection oil as calibration media to reduce the instability. Then from **FIGURE 2** can be analyzed the rhythm of the rise and fall measured temperature movement were same for each DS18B20 Waterproof sensor to ASTM 117C thermometer. Therefore there is no dviant pattern between sensors at measured point.

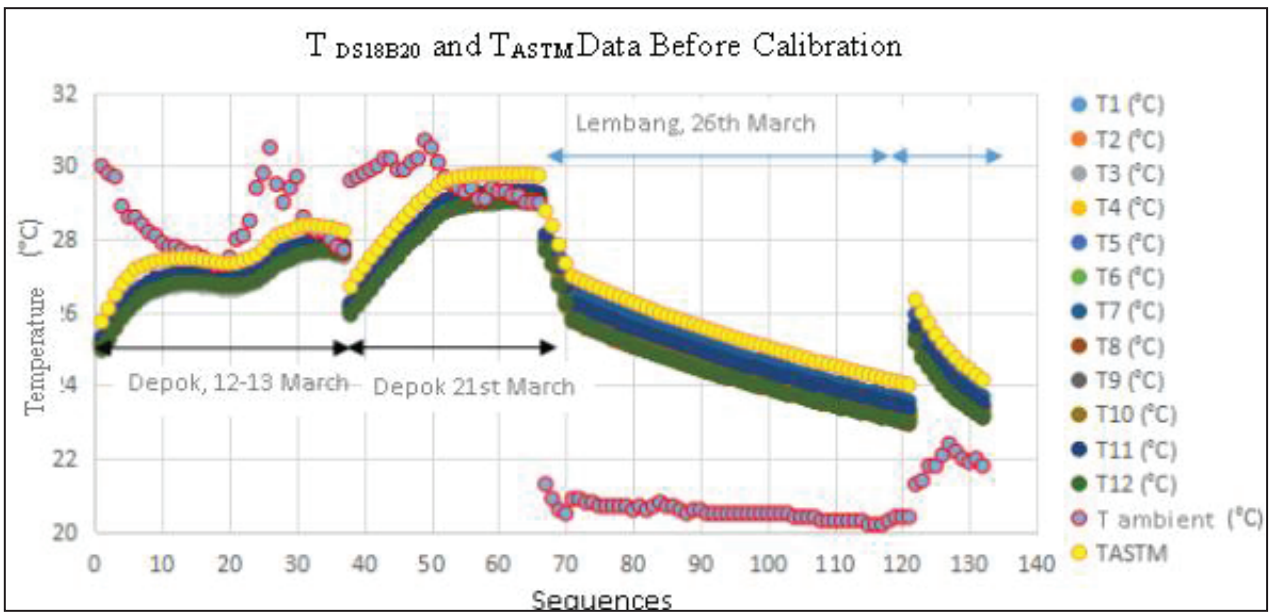

FIGURE 2. Temperature Measured Before Calibration

Measured temperatures of DS18B20 Waterproof sensors were not same each other even though those just been purchased and have the same specifications and manufacturer. Difference in temperature readings from those 12 sensors will then be combined to find measurement deviations that represent DS18B20 Waterproof sensor in general. Of all measurements that have been made, there is 0.31 ° C - 0.82 ° C measurement deviations between sensors. In addition, from FIGURE 2 can be analyzed that measured temperature between sensor and thermometer also have a difference or error. Error value shown by RMS error in percent (%) is the percentage of the root of the average square of the difference in the value of the temperature measurement by the DS18B20 sensor and ASTM 117C. The value of RMS error before calibration is 3.00% and will be compared with the value RMS error after calibration.

Determined Error Characteristic Line

From the data obtained, then made temperature graph (^{o} C) sensor DS18B20 Waterproof vs. temperature (^{o} C) thermometer ASTM 117C to compare the performance of the two measuring devices as in FIGURE 3. Then obtain deviation equation from DS18B20 Waterproof sensor to ASTM 117C thermometer. Deviation equation obtained is linear line equation from regression. Linear regression selected because there are no specific physical phenomena that will be observed from variables x and y but only the performance comparison between two measuring instruments. Another reason is ASTM 117C thermometer as a calibrator is a mercury thermometer that has linear characteristics

From FIGURE 3, regression line equation is $T_{DS18B20} = 1.0519T_{ASTM} - 2.155$. This equation represents the deviation characteristic of DS18B20 Waterproof sensor against calibrator that is ASTM 117C thermometer. From the regression model, determination coefficient (R^2) value of 0.989 close to 1. R^2 value obtained means that 98.9% of regression lines of this model are considered suitable to explain the deviation characteristics [8]. This regression equation only applies to the ASTM 117C temperature range of 23.9^{o}C - 30.1^{o}C. The deviation has zero and sensitivity drift against ASTM117C temperature line or $T_{DS18B20} = T_{ASTM}$. Regression line equation needs to be carried out further analyzes because it has uncertainty, so that regression equation can be assessed and scientifically accountable. The following is a table of regression equations before calibration.

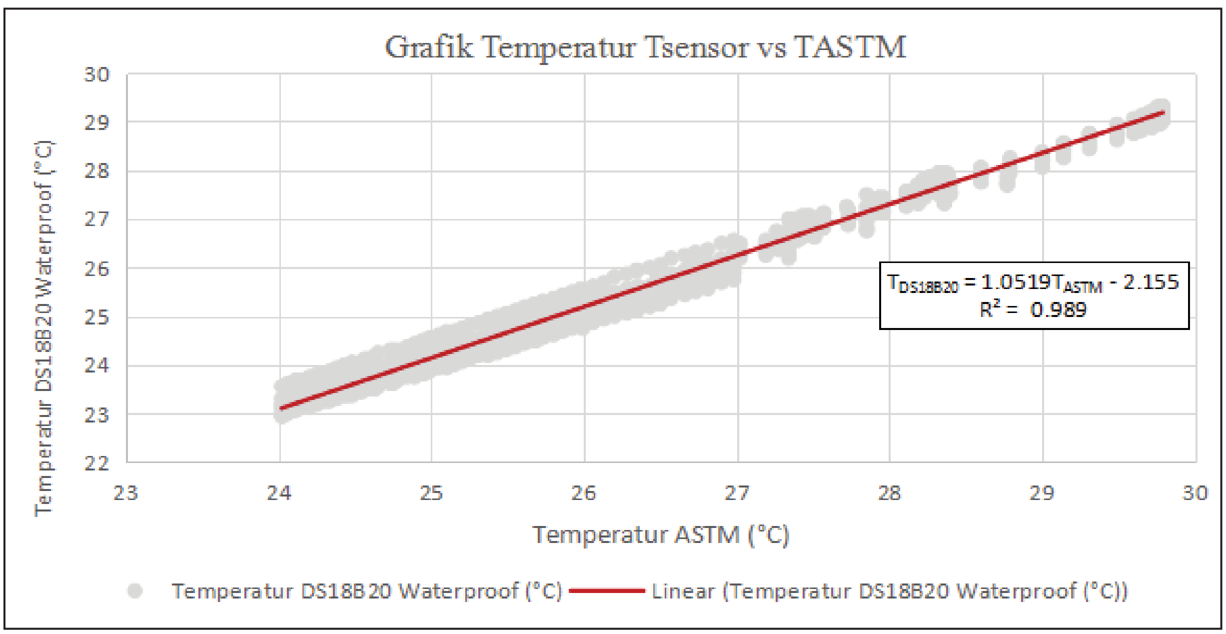

FIGURE 3. Linear Regression

Uncertainty on Regression Line

The uncertainty of regression line were deviations and confidence intervals on the gradient (m), intersection (b), regression lines, predictive intervals and the coefficient of determination. From **TABLE 1.** the percentage deviation of all these parameters have value below the 5% deviation, so that the calibration equation can be used and can be accounted for applications in the engineering field.

TABLE 1. Regression Parameters

No	Notation	Parameters	Before Calibration
1	$s_{y,x}$	Standard Error Estimation	0.183352609
2	m	Gradient	1.052
3	Sm	Gradient Deviation	0.002660601
4	%Sm	%Gradient Deviation	0.25%
5	Cm	Confidence interval of gradient	1.052 ± 0.00532120
6	b	Intersect	-2.155
7	Sb	Intersect Deviation	0.071523789
8	%Sb	%Intersect Deviation	3.32%
9	Cb	Confidence interval of intersect	-2.155 ± 0.1430476
10	Average of SL	Deviation from Regression Line	0.006338394
11	Average of %SL	%Deviation from Regression Line	0.024%
12	Average of Sxo	Deviation of interval prediction	0.183468317
13	Average of %Sxo	%Deviation of interval prediction	0.707%
14	R^2	Coefficient of Determination	0.989

After obtaining and assessing the regression equation which is the equation of the DS18B20 Waterproof sensor deviation characteristics to ASTM 117C thermometer, then regression equation was used to get calibration equation[9]. Calibration equation to modify the output value of the DS18B20 Waterproof sensor using the inverse principle. This will process the output value read by sensors before it is displayed on the computer, so that temperature can close to the value thermometer which is trusted as true value or TDS18B20 = TASTM. After that calibration equation written on the program and uploaded to Arduino then performing calibration command. Furthermore collecting data to assess the success of calibration method.

Data After Calibration

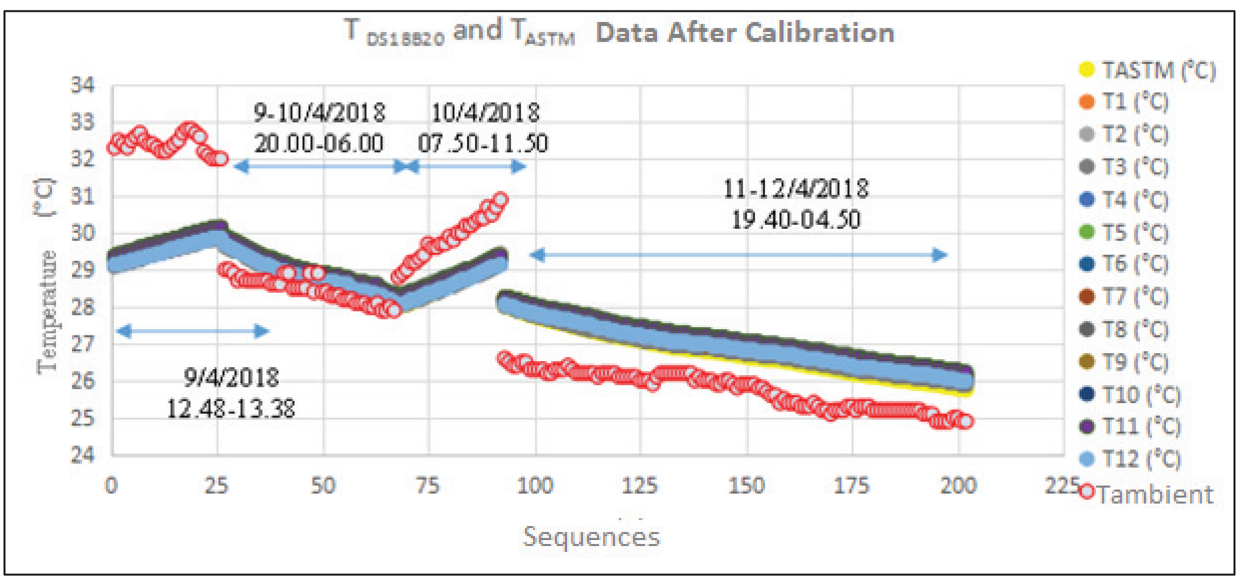

FIGURE 4. $T_{DS18B20}$ and T_{ASTM} data after calibration

Figure 4. is measurement of data after calibration then will be compared to the deviation value and error before calibration carried out. From data retrieval before and after calibration can be compared the deviation between 12 sensors. Deviation between each sensors before calibration has a range of 0.31 ° C - 0.82 ° C. While after calibration this is reduced to 0.23 ° C- 0.42 ° C. From these results can be analyzed that the range of temperature measurement spread by the sensor is tighter, so that it can be concluded that a more precise sensor is obtained. Deviation between the sensors also decreases up to 0.23 ° C which means that the sensor measurements are more accurate or close to the true value. Therefore, calibration can get a more precise and accurate sensor.

Error Comparison Analysis

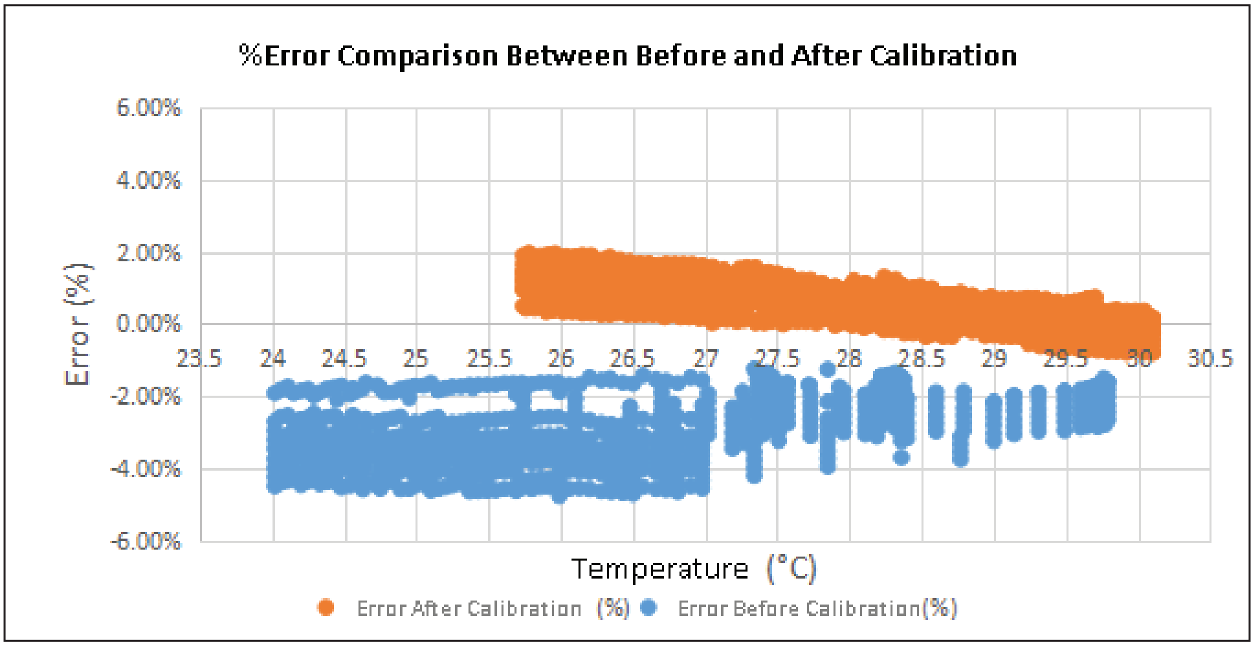

FIGURE 5. $T_{DS18B20}$ and T_{ASTM} data after calibration

Figure 5. is a % error graph of DS18B20 Waterproof sensor against ASTM 117C before and after calibration. Before the calibration, % RMS error is 3.00% with a range of %error -1.24 up to -4.77%. While after calibration is done % RMS error is 0.85% with a range of %error -0.80% up to 1.98%. From this results a range of %error between the sensor and calibrator is closer or in other words the measurement is getting more precise. In addition, %RMS error was reduced from 3.00% to 0.85% after calibration, so that a more accurate measurement was obtained. From the %error analysis between sensor and ASTM it can be concluded that the proposed calibration method is successful to get a more precise and accurate sensor. Apart from these results, from visual graph it can be analyzed that the sensors are more precise and accurate because % error after calibration is very tight and get closer to 0% or the value of ASTM 117C.

Regression Parameters Comparison Analysis

After comparing the error or deviation between each sensors and sensors with ASTM 117C then the value of the regression parameters before and after calibration is performed comparative analysis. Regression is done to look for the deviation characteristics of the DS18B20 Waterproof sensor against ASTM 117C before calibration and after calibration. This is to show whether the measurement process can be scientifically accounted for and show regression model before and after calibration represents all the population of sensor deviation characteristics. . The results of the calculation and comparison of regression parameters are shown in TABLE 2.

TABLE 2. Regression Parameters Comparison

No	Notation	Before Calibration	After Calibration
1	sy,x	0.183352609	0.094885354
2	m	1.052	0.9146
3	Sm	0.002660601	0.001502012
4	%Sm	0.25%	0.16%
5	Cm	1.052 ± 0.00532120	0.9146 ± 0.00300402
6	b	-2.155	2.5479179
7	Sb	0.071523789	0.041740519
8	%Sb	3.32%	1.64%
9	Cb	-2.155 ± 0.1430476	2.54792 ± 0.083481038
10	SL Average	0.006338394	0.003025146
11	%SL Average	0.024%	0.011%
12	Sxo Average	0.183468317	0.094934863
13	%Sxo Average	0.707%	0.340%
14	R^2	0.989	0.994

For the determination coefficient of linear regression model from the two processes of measuring data before and after calibration close to a value of 1 is considered suitable to be able to explain the deviation characteristics of DS18B20 Waterproof sensor to thermometer ASTM117C. Therefore, the two characteristics of the data that is before calibration and after calibration can be used and then compared.

From TABLE 2 standard error estimation ($s_{y,x}$) decreases, standard error estimation is a value that shows the distribution of taken data from regression line. So that, it can be said that sensors to be more precise because data distribution is closer to the regression line. Data distribution value after calibration drops by 48.25% from before. The downfall %deviation value of all parameters indicates that DS18B120 sensor after calibration has a better level of precision compared to before calibration carried out.

CONCLUSION

This research aims to determine the deviation characteristics of DS18B20 Waterproof sensor to ASTM 117C thermometer with the proposed method. This method can be used to calibrate the sensor. From the results obtained characteristics of DS18B20 Waterproof Deviation generally is $T_{DS18B20} = 1.0519_{ASTM} - 2.155$. Characteristic equations are considered acceptable because the deviation of all regression parameters are below 5%. The proposed calibration method can reduce the RMS error between sensor and thermometer from 3.00% down to 0.85% after calibrating and reducing the error range between DS18B20 Waterproof sensors from 0.31 ° C - 0.82 ° C down to 0.23 ° C - 0.42 ° C. This calibration method with arduino-based can produce sensors with increased accuracy and precision. so that obtained a more accurate sensor to be used in testing of Grashof Portable Incubator made by University of Indonesia.

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